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IGNEOUS ROCK-SERIES AND MIXED IGNEOUS ROCKS

I. IGNEOUS ROCK-SERIES

By an igneous *rock-series* we may understand an assemblage of rock-types, differing perhaps widely but still with a certain community of characters, associated in the same district and belonging to the same suite of eruptions, and further, holding a similar position in the scheme of igneous rocks belonging to that suite. Adopting the differentiation hypothesis, we may conceive them as derivatives of the same order from one common source, resulting from differentiation along similar lines and to the same degree. The fundamental characteristics of such a series, having regard to chemical composition, are of two kinds: (1) those belonging to the individual rock-types and shared by all the types included in the series (*e. g.*, each member is rich in some particular constituent, as compared with average igneous rocks of like silica-percentage); and (2) those belonging to the assemblage of types as a whole, depending upon variations in the composition of the members as compared with one another (*e. g.*, a particular constituent may in one rock-series fall off steadily with increasing silica-percentage, in another series it may rise to a maximum and then decline). These characteristics, and especially those which fall under the second head,

come out most clearly when exhibited graphically in a diagram such as was first used by Professor Iddings.[1]

The diagram is easily constructed from the analyses of the rocks (Fig. 1). Two rectangular axes, *OX* and *OY*, are drawn, horizontally and vertically, each of length equal to 100 parts of some convenient scale. We cut off the abscissa *OM* to represent the silica-percentage of any one of the rocks, and erect ordinates *MP*, *MQ*, etc., to represent the corresponding percentages of the other oxides, which we may conveniently speak of as the bases. This is done for each of the rocks. Then joining *P P'* . . . ., etc., we have a line which represents the variation of one particular base in this rock-series, and similarly for the other bases. Iddings converts the figures of the analyses into molecular proportions before expressing them graphically; but for our present purposes nothing would be gained by doing this, and we may follow the simpler method.

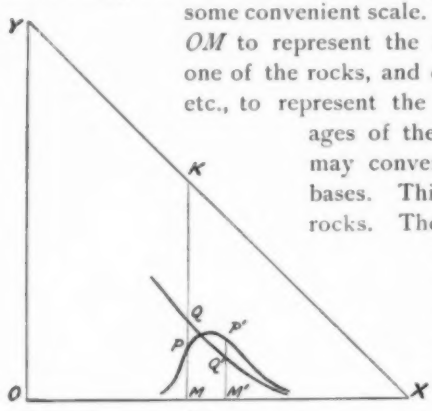

FIG. 1.

The lines *PP'* . . . ., etc., *QQ'* . . . ., etc., as thus laid down, are broken or zigzag lines. We find, however, that in a rock-series in the strict sense of Brögger the departures from regularity are not great. Minor irregularities may arise from the variation found among different specimens of the same rock-type, or from errors in the analyses. To obtain a clearer picture of the essential variations characteristic of the series it will be legitimate to *smooth* the lines, *i. e.*, to convert them into flowing curves passing as nearly as may be through the proper points. The diagram then affords a graphic representation of the chemical characteristics of the given rock-series. We may use it, for

[1] Origin of Igneous Rocks, Bull. Phil. Soc. Wash. (1892), Vol. XII, pp. 89–214.

example, to obtain by interpolation the chemical composition of a member of the series intermediate between two known members. To predict by extrapolation the composition of a hypothetical member beyond the limits covered by actual representatives is, of course, a more speculative matter, since we have no precise data for prolonging the empirical curves. There are, however, some obvious considerations. The sum of all the ordinates *MP*, *MQ*, etc., for a given rock must be equal to *MK*, *K* being the point in which the vertical through *M* meets the straight line *YX*. Hence all the curves must be contained within the triangle *YOX* : prolonged to the right, they must all meet at the point *X*, corresponding with a hypothetical rock with 100 per cent. of silica : prolonged to the left, they must meet the line *OY* in points such that the sum of all the ordinates is equal to *OY*, corresponding with a hypothetical rock devoid of silica.

The simplest kind of variation conceivable is found when, with increasing silica-percentage, the percentage of each base changes at a constant rate (different for each). In other words, the percentage of each base is then a linear function of the silica-percentage. Such a series may be termed a *linear series*, and its geometrical characteristic is that all the curves in the diagram become straight lines. In the wholly ideal case of a linear series extending to the ends of the scale, all these straight lines would decline towards the right and meet at the point *X*. It is safe to say that no such series exists in nature, nor has any natural series been described corresponding with a portion of such a diagram. It may, however be inquired whether, or to what extent, natural rock-series fulfill the condition of linearity within the limits of the actual representatives of the series. Professor Brögger, in his memoir on the grorudite-tinguaite-series,[1] makes approximate linearity a characteristic property of a *Gesteinsserie* : this is implied in his dictum "every mean of a number of members of the series corresponds approximately with a possible member of the series." But it is easy to show by plotting graphically the analyses which he gives that this

[1] Eruptivgesteine des Kristianiagebietes (1894), Part I, p. 175.

must not be understood in too literal a sense. Indeed, Brögger himself abandons the principle; for, in calculating by extrapolation the composition of a hypothetical end-member of the series, he supposes that, while some of the bases vary in arithmetical, others vary in geometrical proportion: a supposition inconsistent with linearity.[1] If a few rock-series be actually plotted in diagrams, it soon becomes apparent that, while some of the bases often give sensibly straight lines within the limits of the actual rocks, others give lines very decidedly curved. We may note in passing that some kinds of variation in igneous rock-masses connected with differentiation *in situ* involve much more considerable departures from the linear type. Such, for instance, is the "concentration" of the more basic constituents in certain parts of a rock-body, as investigated by Vogt and others.

It appears then that in general the diagram of a rock-series will consist of *curved* lines to indicate the variations in percentage amount of the several bases. Of these curves we may distinguish two kinds: (*a*) When the constituent in question first increases to a maximum and then decreases, or increases first more rapidly and then less rapidly, or decreases first less rapidly and then more rapidly, the curve will be *convex* upward; (*b*) When it decreases to a minimum and then increases, or decreases first more rapidly and then less rapidly, or increases first less rapidly and then more rapidly, the curve will be *concave* upward. This classification is not an exhaustive one, for there may be curves which are inflected, being convex in one part and concave in another, but it will be sufficient to consider the simpler cases. Since the sum of the ordinates for all the bases falls off steadily in linear fashion, its curve of variation being the straight line *Y.Y*, it follows that in any series, other than an ideal linear one, some of the bases must give convex and others concave curves.

II. MIXED IGNEOUS ROCKS

Considerable differences in composition may exist among members of the same rock-series, and still greater differences are

[1] *Ibid.*, p. 172.

found among members of different series belonging to the same suite of eruptions in one district. Most of those who have discussed the origin of igneous rocks have sought the cause of this diversity in various processes of diffusion, etc., commonly spoken of as *differentiation* in rock-magmas; it is no part of our present object to discuss these processes. Some geologists, however, including Professor Sollas and Dr. Johnston-Lavis, have laid stress on the possible origin of certain igneous rocks by *admixture*, a process in some sense the reverse of differentiation, and this question we shall consider more closely.

We may distinguish *a priori* three cases:

1. Mixture of two fluid rock-magmas.
2. Permeation or impregnation of a solid rock by a fluid magma with consequent reactions between the two.
3. Inclusion of solid rock-fragments (xenoliths of Sollas) in a fluid magma and their partial or total dissolution and incorporation in the magma.

In the first case the two rocks involved must be of the same age and presumably from a common origin. In the second and third cases this is not necessarily true, and the solid rock need not even be an igneous one; but, when we examine actual instances which have been described, it seems probable that here also admixture does not in fact take place on an important scale except between igneous rocks of cognate origin. Lacroix, in his exhaustive memoir on xenoliths,[1] distinguishes two categories, *enclaves énallogènes*, which are not related in composition or by origin to the enclosing rock (*e. g.*, limestone fragments in trachyte), and *enclaves homœogènes*, which do present more or less resemblance in composition and origin to the rock in which they are enclosed (*e. g.*, olivine-nodules in basalt). Similarity of mineralogical composition is, however, by no means a sufficient test of community of origin among igneous rocks, and instances may easily be cited (*e. g.*, some cases of gabbro enclosed in granite) which would be placed by Lacroix under the former of his two heads, but in which there exists, despite differences of

[1] Les enclaves des roches volcaniques, Macon, 1893.

composition, an essential and close relationship between the two rocks thus associated. Instead of using the above terms in an altered sense, it will be better to coin new ones, and we shall accordingly recognize two kinds of xenoliths, *accidental* and *cognate*. This distinction is based, not on difference or likeness in composition, but on the existence, in the latter kind, of a genetic relationship between the enclosed and the enclosing rock, which is wanting in the former kind. A like distinction will apply to the permeation of a solid rock-body by a fluid magma. Now although both permeation and the incorporation of xenoliths are known in instances which fall under the accidental category, they are known thus only as quite local phenomena. If new rocks of any considerable extent or importance are actually produced by admixture, it is by admixture of two cognate rocks. One reason for this is doubtless to be found in the consideration that reactions between a solid rock and a fluid magma will be promoted by the former being still at a high temperature when the latter comes into contact with it. There may be other reasons of a chemical nature.

Without discussing at once whether admixture is a factor of prime importance in the genesis of igneous rocks, we may inquire what kind of rocks are to be expected from such a mode of origin. We take first the simplest case, that of admixture between two members of the same rock-series. The chemical composition of the resulting product will be the same whether both or only one of the two rocks be fluid at the time when they are brought together. If the series be a linear one, the admixture will produce a rock having the composition of a possible member of the series. This is Brögger's principle already quoted, which, however, requires to be limited by the condition here imposed. In the more general case the mixed rock will not correspond with a possible member of the series, but will differ more or less in composition from that possible member which has a like silica-percentage. This is clear when expressed graphically (Fig. 2). If *OM* and *OM'* represent the silica-percentages of the two component rocks, and their proportions

in the mixture be *a* to *b*, then *Om* will represent the silica-percentage of the mixture, *m* being the point which divides *MM'* in the ratio *b* to *a*. (The empty portion of the diagram is omitted to save space.) If *PpP'* be the curve of variation of some one of the bases, then *mp'* in the figure represents the percentage of that base in the mixed rock. The percentage in the corresponding member of the rock-series is represented by *mp*, and the mixed rock is therefore deficient in this base as compared with the latter, the defect being represented by *pp'*. Similarly a different base, having *QqQ'* for its curve, will be in excess in the mixed rock as compared with the corresponding member of the rock series, the excess being represented by *qq'*. It is evident that there will be a defect or an excess according as the curve is convex or concave between the points corresponding with the two component rocks. The defect or excess will be greater, *ceteris paribus*, the farther apart the two component rocks are in the series. It is easy to see that, given a series such that its diagram has markedly curved lines, the result of the admixture of two members may be something not only foreign to the series, but highly peculiar by comparison with igneous rocks in general.

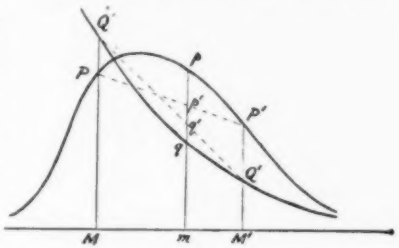

FIG. 2.

This may be still more strikingly the case in the admixture of two rocks which have no such close relation with one another. In illustration we take two simple cases of accidental xenoliths. First suppose a rock-magma to become enriched in silica by dissolving quartz, of extraneous origin, *a* parts of the magma taking up *b* parts of quartz. Dividing *MX* at *m* in the ratio *b* to *a*, we have *Om* to represent the silica-percentage of the resulting mixed rock (Fig 3). If *MP*, *MQ*, etc., represent the percentages of the various bases in the original magma, then *mp'*, *mq'*, etc., will represent them in the mixed rock, these ordinates being

cut off by straight lines joining the points P, Q, etc., to X. If we now draw curves such as Pp, Qq, etc., to indicate in a general way the usual behavior of the several bases in average igneous rocks, we obtain some idea of the respects in which the mixed rock is peculiar. In the diagram it is shown as being unusually poor in the first base and rich in the second. Next suppose a rock-magma to become enriched in lime by dissolving limestone, in the proportion of a parts of the magma to b parts of lime. The result is illustrated by the diagram, Fig. 4. The line OM is divided at m in the ratio a to b. If MP represents the lime in the original magma, mp' will represent that in the mixture, this ordinate being cut off by the straight line joining P to Y. If MQ and MR represent two other bases in the original magma, mq' and mr' will represent them in the mixture, these ordinates being cut off by straight lines joining the points Q and R to O. It is noteworthy that the mixture, as compared with ordinary igneous rocks, may be unduly rich in other bases besides lime: in the figure this is the case with the second of the two bases represented (curve passing through R).

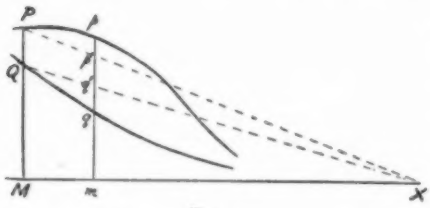

FIG. 3.

The foregoing general considerations lead us to anticipate that a rock resulting from admixture may be, and in many cases must be, of peculiar chemical composition. A rock-series, for example, may consist of basalt, pyroxene-andesite, dacite, and rhyolite; but it does not follow that a mixture of basalt and rhyolite will produce an andesite or a dacite. Still less will a basalt be converted into an andesite by addition of silica, or a rhyolite into a dacite by addition of lime. The processes by which different igneous rocks have been evolved from a common stock are too complex and subtle to be reversible, at least by so crude a method as that of admixture. To illustrate these remarks from

actual instances, we have only to take a collection of trustworthy rock-analyses, such as that published by Clarke and Hillebrand,[1] and plot diagrams upon a convenient scale. The lavas of the Lassen Peak region in California afford a good example. Here the curves of some of the bases approximate to straight lines throughout a considerable part of their extent. Towards the basic end, however, the alumina-line becomes strongly convex and those for magnesia and lime decidedly concave, while the soda-line is slightly but distinctly convex throughout. This diagram includes the normal basalts, andesites, dacites, and rhyolites; and the very slight amount of smoothing required to obtain flowing curves stamps this group of rocks as a natural series. The quartz-basalts, on the other hand, refuse to adapt themselves to this scheme, and their abnormal composition is clearly brought out by plotting their analyses on the same diagram. In their content of lime and potash they do not differ notably from normal rocks of like silica-percentage, but they show a marked deficiency in alumina and ferric oxide, and to a less degree in soda, and an excess of magnesia and ferrous oxide.

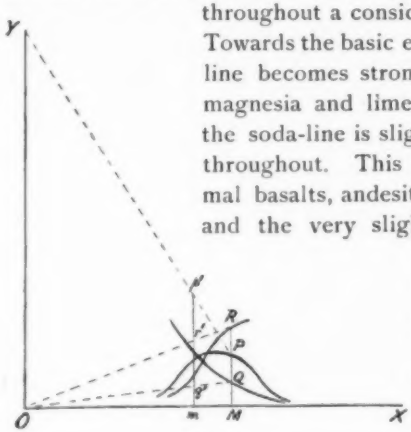

FIG. 4.

Although natural series of igneous rocks differ considerably from one another, they nevertheless possess certain broad characteristics in common. This is recognized by the very general practice of speaking roughly of acid, intermediate, and basic rocks, etc., as having more or less distinctive characters; which tacitly assumes that, in the broadest view, they fall approximately into a single line. Given a large number of analyses of normal (unmixed) igneous rocks, we might average the composition of those having like silica-percentages, and construct

[1] Analyses of Rocks, Bull. No. 148, U. S. Geol. Surv. 1897.

from such averages a diagram expressing the variation of the several bases. Further, we might note the limits of variation of each base within each group averaged, and express these limits also on the diagram. Each base would therefore be represented, not by a simple curve, but by a curved band of varying width. A still further refinement would be to indicate, say by different depths of color within the bands, the frequency of different degrees of departure from the average. On such a diagram it would be possible to test with some precision the principle here advanced, that mixtures, even of two normal igneous rocks and still more of an igneous and a sedimentary rock, must often be abnormal in chemical composition.

So much labor is, however, not necessary for our present purpose. We have hitherto considered only the bulk analyses of the rocks; but we know that a close relation exists between the chemical composition and the mineralogical; a relation which is a matter of very nice adjustment. Expressing it in a crude empirical way, we may say that the chemical variation evinced in normal igneous rocks is not of an arbitrary kind, but is such that the rock-magmas have been able to crystallize as mineral-aggregates consisting of species selected from a comparatively small category, and selected subject to certain laws of paragenesis which control the permissible associations of those mineral species. In a natural assemblage of rock types, whether a "Gesteinsserie," a "Faciessuite," or any other kind of grouping, the limitations are of course narrower still. To inquire into the significance or rationale of such rules would be to enter upon a theoretical discussion of the processes of differentiation, a subject outside our scope: they are introduced here as affording in great measure a test for mixed igneous rocks. For it follows that any variation of an *arbitrary* kind (*i. e.*, not on the lines of magmatic differentiation) imposed on the *chemical* composition of an igneous rock-magma may produce much more considerable modification in the *mineral* composition of the resulting rock. It is well known that, when a magma has absorbed material from sedimentary rocks, this often results in the formation of such

minerals as cordierite, sillimanite, corundum, spinel, idocrase, and others, which are either quite foreign to normal igneous rocks or at least foreign to rocks of the general type of those concerned. A mixture of two igneous rocks will in general show less obvious peculiarity, but it may still be expected to betray itself in the occurrence of unusual minerals, unusual mineral-associations, or unusual relative proportions of the constituent minerals. That it often does so betray itself in a fashion quite unmistakable, is proved by numerous examples of undoubted mixed rocks which have come under the notice of the present writer.

The question here broached has a very direct application to a subject now much in the minds of petrologists, viz., the endeavor to arrive at some natural (as opposed to a merely Linnæan) classification of igneous rocks. Such a classification must be based, confessedly or implicitly, upon fundamental genetic considerations, and primarily upon the mode of operation of the processes of differentiation in rock-magmas. Rocks resulting from admixture must therefore be excluded from the main scheme and relegated to an appendix. Any discussion which tends to the recognition of this principle and to the establishment of some criterion of distinction will forward the object by disembarrassing the problem of a disturbing element.

ALFRED HARKER.

ON THE HABITAT OF THE EARLY VERTEBRATES

If we take the record as it stands, the appearance of the fishes, the first known vertebrates, is one of the most abrupt and dramatic in the life-history of the earth. They seem to come trooping on the stage of action from some concealed source in full company and clothed in varied and curious armor, and at once a battle scene of prodigious range and duration begins. There had been some feeble premonitions, but these had revealed little of the coming drama. That there had been a long series of preliminary trainings, with trials and changes of armor, and rehearsals, and shiftings of parts, we cannot doubt, but where and how this transpired has been an unsolved mystery, though we have tried industriously to get behind the scenes.

The trivial premonitory signs of the apparition, even when interpreted by retrospective light, only serve to render their meagerness the more singular. If the fishes were armored in the Ordovician period, as the Colorado relics found by Walcott seem to show, and if these mail-clad fishes continued to live in the seas and to develop into the panoplied host that made its apparition during the transition stage from the Silurian to the Devonian, why did they not leave a more fitting registration of their presence? The "imperfection of the geological record" is indeed great, but in seas that preserved soft medusæ and delicate graptolites, it would seem that armored fish should have left abundant and substantial signs of themselves, if they were there. The Trenton relics of Colorado, if taken at their fullest assigned value, help to make such a record, it is true, but at the same time they emphasize its scantiness and nullify the familiar appeal to an unfossilizable softness of structure and perishableness of parts. While they contribute a little to the record, the chief effect of their discovery is to greatly strengthen the opinion long entertained that the fishes must have had a very protracted

pre-Devonian history, and to reënforce the conviction that the evolution of full suites of armor and varied forms of dentition was the work of a prolonged period and had almost necessarily many fossilizable stages previous to the striking display in the Devonian period and this conviction becomes the more firm when it is considered that the differentiation and the armoring extended not only to many different orders, but to subclasses and even classes. If Walcott's interpretations be accepted to relieve the dearth of the record, they must also be accepted as showing susceptibility to fossilization so much the earlier.

As the record now stands, there are fragments of plates, scales, and a supposed notochord from the Trenton of Colorado; but a dearth everywhere else in the widespread and well-studied Ordovician and throughout the early and middle Silurian. Then, in the transitional stages from the Silurian to the Devonian, fish remains appear on both continents, and before the Devonian has passed, they present a rich and varied deployment, embracing not only the two classes *Agnatha* (jawless fishes, *Cyclostomata*) and *Pisces* (true fishes) but all the known subclasses of these and a majority of their orders, according to the most recent authoritative classification.

The physical and biological associations of this extraordinary deployment were peculiar. On neither continent do fish remains appear abundantly in the open sea deposits. They are confined chiefly to the sediments of inland waters or of littoral zones or of embayed arms of the sea. The fish of the Corniferous limestone, perhaps most nearly an exception to this generalization, may properly be put in the last class, for the Corniferous beds were laid down in a great bay with only limited connection with the sea, though the fauna was truly marine.

In the Ludlow "bone bed" of England, where they first make their appearance in abundance, the fish remains are associated with Eurypterids, probably the most gigantic Crustaceans that have ever lived, some of them attaining two meters in length. There is the same association on the continent, notably in the island of Oesel in the Russian Baltic and in Podolia and Galicia,

and so again in the Waterlime group of America in which the *Pteraspis Americana* of Claypole occurs. The physical conditions in all these cases seem to have been peculiar, and in the case of the Waterlime group they were singularly so, for they permitted a host of these large Eurypterids and other Crustaceans to flourish in seeming luxuriance, while only a meager and pauperate marine fauna found an occasional entrance into the series. The conditions seem to have been congenial to the fish and Eurypterids but not to a typical marine fauna.

In the Old Red Sandstone phase of the Devonian both in Europe and America a similar association obtained. A most extraordinary group of fishes and a family of most gigantic Crustaceans flourished where marine life found only an occasional and meager presence. These few marine forms, here and there in a massive deposit, no more imply prevalent salt water than the present marine species in the Bay of San Francisco imply that the gravels, sands and silts of the valley of California and of the Great Basin, which seem to be analogues of the Old Red Sandstone, are prevailingly marine. The further association of the fishes and Eurypterids with land plants and fresh water mollusks, together with a total absence of marine relics from the same beds, leaves no solid ground for hesitating to accept the dominant view of English and other geologists that the typical Old Red Sandstone and its homologues are the deposits of fresh waters and that both the fishes and the Eurypterids found congenial conditions of life in them. As fishes and Eurypterids were found both earlier and later in marine deposits the question arises: *Were the fishes and Eurypterids primarily marine and later became adapted to fresh water, or were they primarily fresh-water forms which were occasionally carried out to sea, and which later became adapted to salt water?* The two cases do not necessarily require an identical answer, but the singular association of the two in unusual display under peculiar conditions and on both continents strongly implies a community of habit, at least at the stages in question. The association is one of the most unique faunal and physical combinations of geologic history.

The earlier occurrence of the Eurypterids in marine deposits is almost as limited as that of the fishes, and yet they were well adapted to fossilization and were actually fossilized as far back as pre-Cambrian times, as Walcott has recently shown by their discovery in the Belt Mountain terrane of Montana. Of about a dozen known genera of Eurypterids, only two or three of those least well known are without associations with formations regarded as fresh water. The relics found in marine sediments may be attributed to transportation from the land just as is done in the case of the terrestrial plants and land insects not infrequently found in marine beds; but transportation in the opposite direction cannot be assigned. In the Ordovician but a single Eurypterid representative is known to occur and of this very little is known. In the pre-Cambrian beds of Montana a more abundant presence seems to be indicated, but little has yet been learned of the concurrent physical conditions. The thousands of Crustacean fragments are associated with a few trails assigned to annelids and some that are possibly molluscan or crustacean, and the inference is that the deposits were made in the sea. From the occurrence of Eurypterids first in marine beds apparently and later in fresh-water deposits it has been inferred that they were originally sea-dwellers and later became adapted to landwaters, but the meagerness of their marine record on the one hand, and their abundance and fine preservation in the fresh-water deposits on the other, give point to the question whether their early marine record is anything more than the chance deposit of river forms borne out to sea. When it is considered that the records of acknowledged marine types are, on the whole, good as such things go, and have been widely and well-studied, there is an incongruity in the case of both the fishes and the Eurypterids between the meager marine records of the Ordovician and Silurian, and the impressive fresh-water record of the same forms in the Old Red Sandstone phase of the Devonian, and this incongruity may well be regarded as significant.

There is reason to believe that opinion has been much influenced — more or less unconsciously no doubt — by general

presumptions, rather than specific ones. There is a strong general presumption, based on theory and observation, that the earliest life was marine and hence that in the gross the course of migration has been from the sea to the land and to the air. But this should weigh nothing in particular cases not in conflict with it, for the descent of reptiles and mammals from the land to the sea is well established, and this in no way contravenes their remote ascension from a marine ancestry. It may be equally true that the fish and the Eurypterids descended from the rivers to the sea in the mid-Paleozoic, though their remote ancestors may have ascended from it.

In dealing with the specific presumptions of the case it is to be noted that the relics of river faunas are imminently liable to be borne down to the sea, while transportation in the opposite direction is unassignable. The presumption is that a land or fresh-water fauna will be somewhat represented in contemporaneous marine sediments if it be readily fossilizable. The fragments of fish and Eurypterids in the marine beds previous to the transition stage at the close of the Silurian are not more than could be expected if fish and Eurypterids were living in the streams of those times, but entirely absent from the seas. Indeed the record is rather scant even on this assumption.

A more or less widely accepted presumption regarding the early states of the land has possibly also weighted against the hypothesis that the fishes had their early development in the land waters, viz., the presumption that the land was without vegetal clothing, and that hence its waters were sterile and unsuited to life. Against this presumption there are several important considerations. If the land were naked, not only would the streams be sterile and silty from the unrestrained wash of the surface, but the waters of the sea border would also be similarly affected in some notable degree. Sea life should have avoided rather than sought the sterile, silty, shore waters. But the abundance of littoral life in the early Paleozoic fails to support this view.

Moreover, if the land were unprotected by vegetation, the rate of transportation of loosened surface materials would probably have been too great to permit complete chemical disintegration. As fast as crystalline grains were separated from their fellow grains by disintegration acting at their contacts, or along cleavage planes, they would doubtless have been promptly carried away to sea and the sands and silts would have been arkose in type. But as far down as the Cambrian at least they are distinctly not so, as a general rule. They are as pronouncedly disintegration-products as in any later age. The Upper Cambrian sandstone of the American interior is a most typical example of a thoroughly disintegrated product. The Huronian series, as developed about the Upper Great Lakes, bears scarcely less distinctive evidence of the dominance of disintegrating agencies than the Mesozoic and Cenozoic terranes on whose origins the influence of an ample clothing of vegetation wrought its full effects.

Still further, the voluminous carbonaceous deposits of the Huronian give support to the assumption that at least lowland vegetation then prevailed in abundance. These carbonaceous deposits have been compared in respect to the amount of carbon with the coal beds of the Carboniferous and Cretaceous periods, and not without some show of justice.

There are good reasons therefore for displacing the presumption, rather current in the earlier half of the century, that the lands of the older Paleozoic periods were barren of vegetation and for the substitution of the presumption that land vegetation was prevalent as far back as the shore deposits display the residuum of complete disintegration and abound in the relics of sea life. Beyond that, where the schists do not radically differ in chemical constitution from the igneous rocks, the era of a naked earth and the reign of disaggregation with slight decomposition may be placed amid the other mysteries of the Basement Complex.

The richness of littoral marine life, at least as early as the Cambrian, the carbonaceous deposits of the Huronian and the

chemical nature of all the Paleozoic and most of the Proterozoic strata, afford, in my judgment, ample ground for the presumption that vegetation clothed the land from a date long anterior to the Paleozoic era and that the land waters were capable of supporting their own appropriate fauna, as well as contributing to the support of that of the sea border.

Now there is one distinctive characteristic of land waters that deserves consideration in the study of the evolution of the early vertebrates, because it was a strenuous dynamic condition constantly impressed upon their fauna. It is their most familiar and essential feature, *their flow*. Neglecting lakes, which are mere incidents, land waters are distinguished by persistent and usually rather rapid motion in a fixed direction, and this is an insistent physical condition to which their fauna must adapt itself. Fortunately this adaptation must take a tangible form, whereas adaptation to the freshness of the water is accomplished by obscure modifications which are not as yet detectable. In flowing water, the animal must maintain its position against the current either by a contact of some resisting kind with the bottom of the stream, or must be provided with an effective mode of propulsion competent to meet the constant force of the current without undue draft on the vital resources; otherwise the animal would be swept out to sea and its race be ended as a stream-dweller. It is different with ocean currents, for they return upon themselves and an animal may yield to them without losing its marine habitat; and besides, they are usually much feebler than river currents.

A glance at the faunas of existing streams, which represent the outcome of ages of trial, shows only three prominent groups of animals that have accomplished the adaptation. The minor instances are negligible. The successful cases are, first and foremost, fish, second, certain mollusks that crawl on the bottom with firm contact, and third, certain crustaceans that are provided with numerous sharp claws that give them ready catch and hold upon the stream bed. The brachiopods that are free in youth, but sessile or pediceled in later life, the cephalopods that are

floating or swimming forms, the corals, the chrinoids, the echinoids, and many other sea forms of ancient history and long opportunity, have not made an effective entrance into the streams during geologic time; and this is probably not wholly, and perhaps not chiefly, due to the sweetness of the waters.

A compact form of body presents obvious advantages, except as environment or food or locomotion requires some departure from it, and the vast majority of animals are more or less rotund, and their locomotive devices are adjusted to this form. But the rotund form offers much resistance to rapid currents and unfits the animal for effective stream life unless it persistently hugs the bottom. Neither the rotund floaters and swimmers like the ancient cephalopods, nor the cilliated spawn of the sessile forms are well adapted to resist the unceasing pressure of a rapid stream, and these are practically absent from river faunas.

There is only one conspicuous type that is facilely suited to free life, independent of the bottom, in swift streams, and that is the fish-form. The form and the motion of the typical fish are a close imitation of the form and motion of wisps of water-grass passively shaped and gracefully waved by the pulsations of the current. The rhythmical undulations of the lamprey which perhaps best illustrates the primitive vertebrate form, and is itself archaic in structure, are an almost perfect embodiment in the active voice of the passive undulations of ropes of river confervæ. The movement of the fish is produced by alternate rhythmical contractions of the side muscles, by which the pressure of the fish's body is brought to bear in successive waves against the water of the incurved sections. In the movement of a rope of vegetation in a pulsating current, it is the pressure of the pulses of water against the sides of the rope that give the incurvations. The two phenomena are natural reciprocals in the active and passive voices.

The development in the fish of a rhythmical system of motion responsive to the rhythm impressed upon it by its persistent environment and duly adjusted to it in pulse and force, is a

natural mode of neutralizing the current force and securing stability of position or motion against the current, as desired. Beyond question the form and the movement of the typical fish are admirably adapted to motion in static water and that has been thought a sufficient reason for the evolution of the form, and so possibly it may be, but fishes in static water have not as uniformly retained the attenuated spindle-like form and the extreme lateral flexibility as have those of running water. Among these latter it is rare that any great departure from the typical "lines" and from ample flexibility has taken place, while it is not uncommon in sea fishes. Among the latter not a few have lost both the typical form and the flexibility. The porcupine-fish, the sea-horse, the flounders, and many others are examples of such retrogressive evolution, which is doubtless advantageous to them within their special spheres in quiet waters, but would quite unfit them for life in a swift stream. And if the view be extended to include the low degenerate forms, like the Ascidians, that are by some authors classed as chordates, the statement finds further emphasis.

It is not difficult for the imagination to picture a lowly aggregate of animal cells, still plastic and indeterminate in organization, brought under the influence of a persistent current and caused to develop into determinate organization under its control, and hence to acquire, as its essential features, a spindle-like form, a lateral flexibility, and a set of longitudinal side-muscles adapted to rhythmical contractions, since these are but expressions of conformity and responsiveness to the shape and movement normally impressed by the controlling environment upon plastic bodies immersed in it. The necessity for a stiffened axial tract to resist the longitudinal contractions of the side muscles and thus to prevent shortening without seriously interfering with lateral flexibility, is obvious and is supplied by a notochord. Thus, by hypothesis, the primitive chordate form may be regarded as a specific response to the special environment that dominated the evolution of a previously indeterminate ancestral form.

That some primitive animal aggregate far back in pre-Cambrian time should have found refuge from marine persecution or competition in the sweet running water that entered the sea at so many points, and should have evolved on lines in strict conformity with the dominant force of its new environment does not seem improbable.

If such were the origin of the vertebrate type, its subsequent history and the peculiar phases of fossilization previously discussed are natural sequences.

Distribution from river to river would be slow but inevitable, without the aid of the bizarre agencies of water-fowl, whirlwinds, etc., sometimes appealed to in modern instances. The degradation of the land by streams involves inevitably much piracy, and at the stage of capture the two streams are united for a certain period; and for a still longer period they relieve each other of surplus waters in times of local floods which happen to affect one basin more than the other. Measured by the time requisite for fish migration, these periods of continuous and occasional communication are long. The event itself is, to be sure, infrequent. But in the history of a river basin, the piracy of some one or another of its numerous branches interlocking with the branches of neighboring basins is probably not especially rare. In the next geological period the number of piracies between the headwaters of the Mississippi, the St. Lawrence, the Hudson Bay system, and the Mackenzie will certainly not be few, and before the Cordilleran tract is base-leveled, it may safely be affirmed that piracies at many points will have furnished a migratory tract between the river systems of the interior and those of the Pacific.

Certain attitudes of the sea to the land develop lagoons and sounds behind spits, fringing inlands, and barrier tracts, and if the land be growing at the expense of the sea, the waters of these lagoons and sounds often become wholly cut off from the sea and so pass from the salt to the fresh condition, and thus afford a means of migration from river to river near their mouths. The attitudes which favor this kind of communication occur

inevitably in the changing relations of land and sea that attend the normal progress of geologic periods. Thus, on the headwaters by piracy and along the sea by lagoons, there are systematic sources of intercommunication by which fresh-water faunas may migrate from basin to basin and may thus occupy quite fully their appropriate domain without dependence upon accidental means or coast-wise communication by temporary entrance of the sea, which may be a resource in some cases. Measured by geologic periods, these means of migration are doubtless sufficiently frequent to be altogether adequate.

The extensions and the changes of domain thus provided to the hypothetical primitive chordate organism may be assumed to have sufficed for its expansion and differentiation through a long period without giving rise to any such degree of overcrowding as to force it to take to the sea for relief; and such intrusions upon the sea as occurred during this initial era may be regarded as individual and accidental.[1] If this be so, it may be inferred that even after the primitive chordates had become differentiated into the ancestral classes, and even into the main ordinal types of the fishes as we now know them paleontologically, and had also attained some measure of induration of parts, the preservation of these parts in the sea sediments would be rare; and this is in accord with experience.

In time, however, the streams must inevitably have become overstocked and a severe struggle for existence must have ensued attended by the acquisition of organs of attack and defense; and at length there must have been an irruption into the sea to avoid the greater enemies and the stronger competition at home. To such an irruption is assigned the remarkable apparition of agnathous and gnathous fishes at the close of the Silurian in varied type and clothed in full armor, expressing the urgency of the competition; though a notable part of the

[1] From early individuals that failed to hold their place in the streams for any reason, and succeeded in maintaining themselves in the sea to which they were carried, there may have sprung the lower chordate types like the ascidians and Balanoglossus, if they really belong to the vertebrate phylum.

apparition, it must be observed, was due to the exceptional preservation of the land record. Thereafter, by interpretation, the habitats of both the Agnatha and the Pisces were more general and varied, a portion taking permanently to the sea, and a portion remaining in the land waters, while a third portion migrated between the two. The well-known habit of many of the last to return to the swift inland streams to initiate each new generation is suggestive of ancestral conditions. The sharks, the hagfishes and many Teleostomes represent divisions that became permanently sea faring. The lung-fishes (Dipnoans), the old-type Crossopterygians, a part of the lampreys, and many others seem to have mainly adhered to the fresh water, at least their present representatives now frequent these waters, either exclusively or in the main. The fossil record of this latter group, throughout the later geologic ages, is well nigh as scant as that previous to the Devonian, and this would seem to be a very significant fact. The lampreys seem to have been ancestrally represented in the Devonian by the little *Palæospondylus gunni* recently found in beautiful preservation in the Achanarras quarry in North Scotland, where conditions for the preservation of fresh-water deposits were exceptionally good. After this single appearance the lamprey type was lost to sight until modern times revealed its probable descendants in the lamprey of our present waters. In like manner, the Dipnoans, after a notable record in the Devonian and Carboniferous periods, where fresh-water life was exceptionally preserved, nearly disappeared from the record, but are now found in three forms, one in each of the three southern continents, Africa, Australia, and South America. So, too, the singular Crossopterygians, though their deployment may have been wider, after a fine display in the Devonian and Carboniferous, passed into a decline in the early Mesozoic and disappeared in the Lias, but are now found in the fresh waters of Africa. Special interest attaches to the Dipnoans and Crossopterygians as the probable ancestors, or the nearest known kin to the ancestors of the amphibians, and through them, of all reptiles, birds, and mammals, because it

carries a certain measure of presumption that the amphibians were fresh-water derivations.

In this larger application of the interpretation herein suggested, the chordate phylum is made to be essentially from first to last a terrestrial race, whose main habitat was the land waters and the land itself, though still a race that sent its offshoots down to sea from time to time from the mid-Paleozoic onwards.

The large hypothetical element in the foregoing interpretation is sufficiently evident and needs neither word of caution nor apology. The problem at present admits of no other than hypothetical treatment. The discussion is merely the attempt of a geologist to interpret from the geologic side the imperfect data that bear obscurely on the habitat of the early vertebrates.

T. C. CHAMBERLIN.

THE BIOGENETIC LAW FROM THE STANDPOINT OF PALEONTOLOGY.

THE interest of the paleontologist in embryology, and in ontogeny in general, lies wholly in the wish to know the origin and relationships of biologic groups; a scientific interpretation of ontogenic data in terms of phylogeny depends on the extent of preservation of the ancestral record in individual development. The broad statement has often been made that each animal gives in its own development an epitome of the history of its race. Because of the law of heredity, this statement would be true, and the record would be complete, if nothing had interfered with the normal course of things. But, in reality, so many secondary elements are introduced in development, that authorities are very much divided as to the value of ontogenic stages as records of race history.

There can be no doubt that students of postembryonic stages have been inclined to claim too much for the law of tachygenesis, while, on the other hand, students of embryology have been inclined to discredit it almost entirely, and to lay little stress on ontogenic stages as a recapitulation of phylogeny. The reason for this disagreement is not far to seek; it lies in the field and in the methods of research of the two groups of morphologists.

Types of development.—Leaving out of consideration the *Protozoa*, which come into being with the essential characteristics of the adults, there are, in the *Metazoa*, two types of development: (1) the *fœtal type*, in which the development takes place in the egg, or in the body of the parent, and the young animal comes into the world in form closely resembling the adult; (2) the *larval type*, in which the young animal comes out at an earlier stage of development, and reaches maturity only after considerable metamorphosis.

Secondary elements will be introduced in either type of development, and those variations that are favorable to the preservation of the species are likely to be perpetuated by heredity. Now in the fœtal type the most favorable variation consists in abbreviation, thus simplifying the development. Any characters that are useful in a free state, but not in a fœtal state, are liable to be lost. Thus in the fœtal type the tendency is toward loss of the record through omission of stages or obscuring them, for many organs that would be highly developed in mature forms, or in free larvæ, will be either suppressed or undifferentiated.

The vertebrates, most of the higher crustaceans, most land and fresh-water mollusks[1] have the fœtal type of development; and these embrace by far the larger part of animals whose ontogeny has been studied. It is not to be wondered at, then, that morphologists who deal exclusively with embryonic stages of these groups should be skeptical about the repetition of family history in individual development. Here many stages are omitted, and the rest so obscured and undifferentiated as to be unintelligible; and secondary characters, due to life in the egg or in the parent, are introduced, effacing what little meaning was left. Then, too, embryologists are often content to trace the animal but a little way toward perfection of development; they study the embryo until the cells begin to divide into groups indicating a beginning of organs, and call this studying ontogeny, when they have stopped before it could be told whether the animal was going to develop into fish, flesh, or fowl. To this sort of study is due the idea of "falsification of the record," a crime of which nature has not yet been guilty, although she at times may not, perhaps, have told the whole truth.

Primary and secondary larvæ.—If the way of the embryologist lies in stony places, that of the student of postembryonic stages is not much smoother; formidable obstacles meet him on every side, reducing his small stock of faith. At the very outset he is confronted by the difficulty that there are two distinct types of

[1] *Dreissensia*, a fresh-water pelecypod, which in very recent geologic time has immigrated from salt water, still goes through its larval development, like its marine relatives.

larvæ: (*a*) *primary larvæ*, such as are more or less modified from ancestral forms, and have continued to develop as free larvæ since the time when they constituted the adult forms; (*b*) *secondary larvæ*, such as have been introduced by cenogenesis into the ontogeny of species that formerly developed by the fœtal process. If ancestral characters have been retained in the egg, then these secondary larvæ may bear some palingenetic characters, and thus be hard to distinguish from primary larvæ; otherwise they will be entirely adaptive, or cenogenetic. A case in point is the development of most insects, whose larval stages are supposed to be largely secondary. Study of individual development in a group of this sort can throw little light on phylogeny.

The student of larval stages must confine himself to the primary sort, if he would correlate them with ancestral genera. The development of the cœlenterates, echinoderms, brachiopods, most mollusks, and the lower crustaceans is direct; thus larval stages of these groups may be bearers, to a greater or less degree, of ancestral characters. But since the free larvæ of even these groups are exposed to natural selection, secondary or cenogenetic characters will be introduced, obscuring the resemblance to ancestral forms; also characters that in the adult ancestral form were functional and fully developed may, in the representative larval stage of the descendant, be so little differentiated as to be unrecognizable.

But how can the morphologist who deals entirely with living species know whether a character is primary, and repeated by palingenesis in the larval history of the descendant, or whether it is secondary, and introduced by cenogenesis into that history? The answer to this lies wholly within the domain of paleontology, for only by finding a stage of growth represented by an ancestral form can the morphologist know that the characters of that stage are ancestral, and not secondary. Larval stages which may be the bearers of ancestral characters must then be compared with the adults of their predecessors, and the paleontologic record must be invoked as a final resort — the court from which there is no appeal.

And this was exactly the method used by Louis Agassiz, who first applied the law of acceleration of development to the study of systematic zoölogy, although it never had much influence on biologic investigation until the palentologic studies of Hyatt in the invertebrates and Cope in the vertebrates placed the law on a sound basis. It was reserved for Alpheus Hyatt to formulate the law and to strengthen theory with practical examples based on study of cephalopods. In his later papers Professor Hyatt[1] has given a more exact and comprehensive definition of the law of acceleration or *tachygenesis:* "All modifications and variations in progressive series tend to appear first in the adolescent or adult stages of growth, and then to be inherited in successive descendants at earlier and earlier stages according to the law of acceleration, until they either become embryonic or are crowded out of the organization and replaced in the development by characteristics of later origin." A still more definite statement by the same author is the following: "The substages of development in ontogeny are the bearers of distal ancestral characters in inverse proportion and of proximal ancestral characters in direct proportion to their removal in time and position from the protoconch, or last embryonic stage."[2]

To insure trustworthy results in verifying this law, the investigator must have groups in which the larvæ are primary and reproduce ancestral characters; in which the living and the fossil are classified on the same basis; of which we have preserved a nearly complete geologic record, and of which material is available for the study of fossil ontogeny as a check on the living. Such groups are especially represented among the *Cœlenterata*, the *Echinodermata*, the *Brachiopoda*, and the *Pelecypoda* and *Cephalopoda* among the mollusks.

Unequal acceleration.— Now, when the morphologist has settled the fact that primary larval stages do actually reproduce, more or less vaguely, characters that existed in the adult forefathers of the generation he is at work on, his troubles are even

[1] Genesis of the Arietidae, p. 9.

[2] Philogeny of an Acquired Characteristic, p. 405.

then not yet ended; for the characters do not necessarily appear in the ontogeny of the descendant in the same association in which they occurred in the ancestor. A character useful to the immature form will have a tendency to be inherited at an earlier age than those useful only to the adult, and so by unequal acceleration of development the parallel between ontogeny and phylogeny is broken. It was once thought that the *Nauplius* larva of the crustaceans was a mature genus, then it was thought to be a larval representative of the extinct radicle of the Crustacea; later still, many morphologists have concluded that the *Nauplius*, while it bears many crustacean characters, still retains too many annelid characters to represent the radicle of the group; it is a typical crustacean larva, but not a representative of the primitive crustacean, and the two sets of characters are thrown together by unequal acceleration. Beecher has shown the same thing in the spiny larvæ of *Acidaspis* and *Arges*, where in the protaspis of these genera the spines characteristic of the adults appear, contrary to usage among the trilobites, in which larval stages are usually smooth. Thus before these animals have assumed characters that would identify them undoubtedly with trilobites they have assumed those most characteristic of their own genera. Jackson has shown that in the larvæ of the *Pectinidæ* unequal acceleration may associate characters that were not synchronous in race history. F. Bernard has recently shown that the prodissoconch of pelecypods is sometimes striated and ribbed, characters that could not have belonged to the primitive pelecypod.

If unequal acceleration causes confusion in the phylembryonic stages, the difficulty is much greater in the larval and adolescent periods, where the shortness of the time of development causes throwing together of characters that were not contemporaneous in the ancestors, and where the small size and general habits prevent differentiation of organs that in the correlative adult forms were highly developed, thus obscuring and even destroying the exactness of the parallelism. Two species of *Placenticeras*, of which the ontogeny has been recently studied

by the writer, must have descended not only from the same perisphinctoid family, but also from the same species of *Hoplites;* and thus, if the parallel were at all exact, they should be alike in the late adolescent stages when they begin to show their generic characters. This, however, is not the case, for they are quite different throughout the cosmoceran stage, and back almost to the end of the larval period, where the transition from goniatite to ammonite took place. If this were interpreted without taking account of unequal acceleration, it would seem that the differentiation of the two species took place back in the Trias, and that different ægoceran forms were the remote ancestors of the two species, which we know could not have been the case.

The writer has recently worked out the ontogeny of two very nearly related species of *Schlœnbachia*, one of which, in its larval period, reproduces very exactly a *Paralegoceras* stage, while the other does not ; the latter species has, however, all the paralegoceran characters, but associated with others that this genus never had, but which belonged to later descendants of this genus. There can be here no question of the veracity of nature in keeping the record, the difficulty lies in deciphering it. So it is not to be expected that any one species would give in plain terms the complete phylogeny of a genus, for stages that are plainly differentiated in one will be obscured in another, and only by studying the ontogeny of a number of species of one genus can the morphologist hope to get a complete history. It is still less to be expected that two separate genera, even when closely related, should tell their story in exactly the same terms, for stages that are emphasized in the ontogeny of the one are obscured and possibly even omitted in the other. And in this case the unequal acceleration goes much farther than with closely connected species. In a comparative study of *Lytoceras* and *Phylloceras* the writer[1] has recently shown how rapid this divergence is, and has drawn the conclusion that unequal

[1] The Development of *Lytoceras* and *Phylloceras*. Proc. Calif. Acad. Sci., Third Ser. Geol., Vol. I, No. 4, 1898.

acceleration would account for a large part of the differentiation observed in successive geologic generations.

Retardation.—Another factor that makes it difficult to correlate ontogeny and phylogeny is *retardation* of development. Cope first recognized the principle, but in his writings confused it with unequal acceleration, and since his reasoning was purely theoretical the idea has never gained much foothold in biologic philosophy. Cope's[1] statement of the theory is as follows: "The acceleration in the assumption of a character, progressing more rapidly than the same in another character, must soon produce, in a type whose stages were once the exact parallel of a permanent lower form, the condition of inexact parallelism. As all the more comprehensive groups present this relation to each other, we are compelled to believe that *acceleration* has been the principle of their successive evolution during the long ages of geologic time. Each type has, however, its day of supremacy and perfection of organism, and a retrogression in these respects has succeeded. This has, no doubt, followed a law the reverse of acceleration, which has been called *retardation*. By the increasing slowness of the growth of the individuals of a genus, and later assumption of the characters of the latter, they would be successively lost." This statement of Cope might apply equally well to unequal acceleration of characters, but in another part of this same work he gives a clearer statement: "Where characters which appear latest in embryonic history are lost, we have simple retardation, that is, the animal in successive generations fails to grow up to the highest point of completion, falling further and further back, thus presenting an increasingly slower growth in the special direction in question."[2]

These remarks of Cope were based on abstract reasoning, but it is possible to bring up some striking cases in support of the theory, notably among the brachiopods. Fischer and Oehlert[3] have shown that while brachiopods go through many metamorphoses in individual evolution, and while each species

[1] Origin of the Fittest, p. 142. [2] Op. cit., p. 13.

[3] Brachiopodes, Mission Scientif du Cap Horn, p. 50–60.

is usually constant in the stages it goes through, it often happens that the individual is arrested in development, never reaching the full generic development of the mature stage. The individual then begins to reproduce its kind before maturity is reached, and tends to give rise to a stock that never reaches the full generic evolution of its ancestors. Dr. C. E. Beecher has well described this: "In each line of progression in the Terebratellidæ the acceleration of the period of reproduction, by influence of environment, threw off genera which did not go through the complete series of metamorphoses, but are otherwise fully adult, and even may show reversional tendencies due to old age; so that nearly every stage passed through by the higher genera has a fixed representative in a lower genus. Moreover, the lower genera are not merely equivalent to, or in exact parallelism with, the early stages of the higher, but they express a permanent type of structure, so far as these genera are concerned, and after reaching maturity do not show a tendency to attain higher phases of development, but thicken the shell and cardinal process, absorb the deltidial plates, and exhibit all the evidences of senility.[1]

If, then, the morphologist tries to study the race history in one of these species thus arrested in development, he cannot read the whole story, for the individual ontogeny will not recapitulate the higher stages lost by retardation.

Another remarkable case is that of the so-called "ceratites" of the Cretaceous. While there have been no goniatites since the Paleozoic, and no ceratites since the Trias, there are found among the ammonites of the Cretaceous some with septa of simple goniatitic character, and others with septa like those of the genuine ceratites. Now since the line of descent is broken, and there is no possibility for a continuous line of these ancient primitive forms to have bridged over the great gap from the Trias to the Upper Cretaceous, we must explain this either by reversion or in some other way. But it is not a simple case of reversion, for, as has been pointed out by several writers,

[1] Amer. Nat., Vol. XXVII, 1893, p. 603.

Douvillé, Nicklès, and others, the septum of adolescent ammonites of this group is not more complex, but really less so, than that of adults, although they are derived from Jurassic genera with complex septa. Thus Douvillé derives the group *Placenticeras-Sphenodiscus* from *Hoplites;* the Pulchellidæ, composed of *Pulchellia*, *Neolobites*, and *Tissotia*, he derives from *Oppelia* of the Jura. Since in each case the ancestral forms are more complex than the descendants, the reduction in complexity of generic evolution can be explained only by retardation or arrested development. F. Bernard has in addition pointed out the fact that the adult of *Pulchellia* is like the adolescent stage of the ancestral *Oppelia*. Now if we define the law of acceleration of development to mean that in a progressive series the young of the descendants correspond to the adults of their more remote ancestors, we find that this does not apply to a retrogressive (retarded) series. In this latter case we must restate the law as follows: the adults of descendants correspond to the young of their more remote ancestors, the higher generic stages to which these ancestors attained having been dropped away by successive retardation or arrested development. The retarded series themselves may become the radicals of new stocks, and so we may have cases where the ontogeny of any one species or genus can never give the full history of the race.

Groups available for correlation.—We see then that the student of morphogeny of animals has to be on his guard, first against the loss of generic stages during the period while the animal is in the egg; then against the introduction of secondary larval stages when the ancestors lacked them; then against the introduction of secondary characters due to adaptation; then against unequal acceleration, bringing together in the ontogeny of the descendant, characters that occurred in separate generations of ancestors; and lastly, against retardation, by which the form never reaches the full generic evolution of its ancestors, and where, if a new series starts out from the retarded form, the complete family history is not recorded in ontogeny.

Is it to be wondered at, then, that the student of morphology becomes a sceptic, or even a rank unbeliever with regard to the value of ontogenic stages as records of history? It is only to be expected that the biologist, especially one that deals almost exclusively with living species, should be inclined to discredit the law of tachygenesis, and to believe that there is such an inextricable muddle of omissions, secondarily introduced characters, and unequal acceleration of those actually repeated, that the record is wholly untrustworthy, or at least illegible. And yet there are so many species and genera in the various groups of invertebrates whose ontogeny is simple, progressive and fairly complete, and whose stages of growth are almost exact repetitions of successive antecedent genera, that it would be impossible to find a student of the morphogeny of the brachiopods, the marine mollusks, or the lower crustaceans, that does not believe implicitly in the value of larval stages of these groups as records of their family history. And this is especially true of the paleobiologists, who regard it of little importance whether the animal under investigation died yesterday, during the flood, or during the Paleozoic era, whether it is preserved in alcohol or in a more permanent museum in the bosom of mother earth; they recognize the fact that the life-history of a Cambrian trilobite has as much bearing on modern biology as does the history of the living crayfish, and that the laws that govern the rise and decline of organisms were just as true then as now.

Not all groups are equally useful to the student of morphogeny, but in each of the lower subkingdoms there are genera of which the ontogeny has been studied and correlated in no uncertain terms with the history of the race. The testimony of these various groups is so uniform, notwithstanding the fact of its having been gathered by men of different beliefs, that its value cannot be doubted. It is also noteworthy that in the higher groups, such as cephalopods and crustaceans, the evidence and the correlations are much more decided.

Cœlenterata.—It has been shown by Dr. C. E. Beecher that the young stages of the Favositidæ correspond to *Aulopora*, or to some other similar unspecialized genus. This same conclusion has been reached by Dr. G. H. Girty based on a study of the ontogeny of *Favosites*, *Syringopora*, and other tabulate corals, all of which are shown to go through an *Aulopora* stage of growth.

Echinodermata.—The only crinoid of which the ontogeny is known is *Antedon*, which has been shown by Sir Wyville Thomson to go through successively stages corresponding to the *Ichthyocrinoidea* of the Paleozoic, and *Pentacrinus* of the Mesozoic, before it becomes free swimming and takes on the characters of *Antedon*.

Dr. R. T. Jackson has been able to prove even in the Paleozoic sea-urchins the possibility of correlating growth stages with phylogeny, in spite of the great difficulties due to resorption of plates, and change of form.

Brachiopoda.—According to Beecher all brachiopods go through a primitive protegulum stage, correlative with the supposed ancestor of the class, although *Paterina*, which was formerly supposed to be this radicle, has been shown to be much more highly specialized than the protegulum stage. The later stages of growth of this class are capable of even more remarkable correlation, as has been shown by Beecher in a number of papers, where every stage of growth is distinctly homologous with well known pre-existing genera; and these same successive genera show a gradual transition in the adults.

Even among the Paleozoic spire-bearers (*Helicopegmata*), this holds good, for Beecher and Schuchert have demonstrated that the early stages of this group are homologous with the terebratuloids (*Ancylobrachia*), aud more especially with the Paleozoic genus *Centronella*, the most primitive of the loop-bearing brachiopods.

Mollusca.—Jackson's correlations of the stages of growth of pelecypods with their race history have already become classic; according to these, every pelecypod begins its bivalve state with

a nuculoid stage, homologous with the primitive radicle of the group. Every *Pecten* goes through stages successively correlative with a nuculoid, *Rhombopteria*, *Pterinopecten* and *Aviculopecten* before it reaches maturity, each stage appearing in the order of the ancestral genus. Even the greatly modified oyster shows its kinship with this group by its nuculoid and *Rhombopteria* stages.

The researches of Branco have made it clear that each group of cephalopods has its typical phylembryo, in a general way correlative with the radicle of the group, and that the later stages may be compared very accurately with ancestral families and genera. The way for this was opened by Hyatt's memoirs on the ontogeny of the ammonites, in which it was shown that in each perfect adult ammonite shell the complete individual ontogeny is recorded. By using this same method Karpinsky has been able to correlate the ontogeny of *Medlicottia* and *Pronorites* with successive ancestral forms, from *Anarcestes*, *Ibergiceras*, *Paraprolecanites*, up to the adult stage.

By the ontogenic method Buckman has been able to get at a sound basis of classification of the Jurassic ammonites, and to correlate the growth stages of many of these with their race history. Although his conclusions as to the systematic position of many of these genera do not agree with the ideas commonly accepted concerning them, it must not be forgotten that these conclusions are based, not merely on ontogenic study alone, but also on the gradual transitions of a series of adults. This is the strongest confirmation that any phylogenic research could ever have.

Crustacea. — Among the most convincing morphogenic researches are Beecher's studies in the ontogeny of the trilobites, all of which are shown to go through a phylembryonic *protaspis* stage, correlative with the primitive crustacean, and similar to the protonauplius of the less specialized living crustaceans. Here, too, it was demonstrated that the larval and adolescent stages of Devonian, Silurian, and even Cambrian trilobites may be correlated with the adults of preëxisting

genera, giving the basis of a natural, or biogenetic, classification of this extinct group.

Many more cases might be added to those cited here, but surely no additional evidence is needed, for all this points in the same direction, whether gathered by believers in or opponents of the theory of evolution. To this latter class belong the evidence brought forward by Barrande in the ontogeny of trilobites, and by Agassiz in the law of recapitulation or acceleration of development. Each of these naturalists used unhesitatingly the method that in the hands of Hyatt and his followers has been so fruitful of results.

JAMES PERRIN SMITH.

THE LOCAL ORIGIN OF GLACIAL DRIFT

NORMAL till is made up predominantly of materials which have not been transported many miles, though some of the minor constituents have often come greater distances. Roughly speaking, the more distant the contributing rock formation, the less its contribution to the till at any given point. There are apparent exceptions to this generalization, but they are chiefly the result either of the unequal exposures of the several formations contributing to the drift, or to their unequal resistance to abrasion.

Locally, the constituents of the drift of distant origin, drop almost to zero. This is true both of drift composed chiefly of clay, and of that which contains abundant coarse material. In extreme cases, stony till is chiefly composed of blocks of rocks that have been moved but little from their original positions. They have been displaced and the clay or sand (the finer portions of the till) have been mixed with them, so that the two sorts of material appear to have been kneaded together. In such cases the rock masses are angular and rough, and frequently increase in size and number from the top of the till to its base. At the base they may be so abundant as to nearly exclude all other constituents. If the surface of the rock be much broken, and its uppermost layers disrupted and crumpled, as is sometimes the case, it may be difficult to say where the line between the bottom of the till and the surface of the underlying rock is to be drawn. Where the rock which gave origin to the drift was not well suited to making bowlders, the comminution of the material gave rise to clayey or earthy matter, as really though less obviously local in origin, as if it had remained in larger pieces. Considering the area of the continental ice-sheets, and the distance which much of the ice traveled, the small proportion of the drift which has come from distant

sources has always seemed a stumbling block to those who are familiar with the facts, but not with their meaning.

In Fig. 1, *a* represents the center of the sector of an ice-cap, and *b d* its circumference. The areas marked 1, 2, 3, and 4 represent successive and equally wide belts of rock of equal resistance and like topography. The center of movement is assumed to be at *a*. When the ice has advanced from *a* to *b d* the deposit of till made at that point is made by ice which, in so far as it has moved from the center, has passed over formations 1 to 4 in succession. In such situations the drift is normally found to contain more material from 4 than from 3, more from 3 than from 2, and more from 2 than from 1.

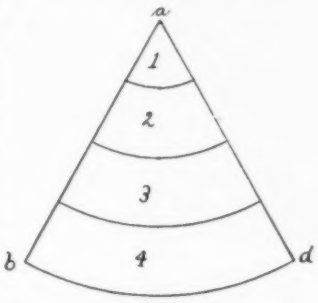

FIG. 1.

It will be understood that if the width of the exposures of the several formations were unequal, or if the several formations were of unequal resistance, the case might be very different. It is also clear that the topography of the several belts will influence the amounts of their contributions, and in view, first, of the varying widths of the various belts of rock passed over by the ice, second, of their varying topographies, and third, of their varying degrees of resistance, many exceptions may arise to the generalization that the contributions of various formations to the till of any locality are in inverse proportion to their distances from the point concerned.

The explanation of the markedly local character of the drift appears to involve several considerations. Fig. 1 illustrates one point involved. Suppose the ice passing over the formations 1, 2, 3, and 4, successively, gathers material with equal facility from each of them. By the time the ice from 1 has spread over 2, the average thickness of the basal layer of drift derived from 1, supposing none of it to have been deposited, would have been reduced to one third its original thickness, since the area of 2 is

three times as great as that of 1. By the time the same ice has spread over 3, the basal layer of drift derived from 1 will have been reduced to one fifth its original thickness, since the area of 3 is five times the area of 1. Still supposing none of it to have been deposited when 4 has been overspread, the thickness of the drift derived from 1 when the ice has covered 4, will be but one seventh of that which it possessed over 1. Even supposing all the drift from 1 to be carried to 4 over the intervening areas, it is thus seen that at such a point as *c*, the amount of distant material should be relatively small. If the ice keeps an equal amount of drift in and beneath itself by gathering enough new material to counterbalance the thinning of that previously held, the till at *c* should be made up as follows:

From formation 1	$\frac{1}{16}$
From formation 2	$\frac{3}{16}$
From formation 3	$\frac{5}{16}$
From formation 4	$\frac{7}{16}$

Thus the spread of the ice will tend constantly to decrease the proportion of basal drift derived from any formation, once that formation is passed.

Since some of the drift derived from 1 would doubtless be lodged as the ice advanced over formation 2, the average thickness of that carried from 1 to 3 will be correspondingly diminished beyond the figure given ($\frac{1}{5}$ of that over 1). Since more of the material from 1 will in all probability be deposited on 3, as the ice advances to 4, the figures given for the thickness on 4 of drift derived from 1 ($\frac{1}{7}$ of that on 1), will need to be still further reduced, and that by a larger amount than that to which the $\frac{1}{5}$ was subject. In view of the continual lodgment of drift, it will be seen that the series of fractions given above, namely $\frac{1}{16}$, $\frac{3}{16}$, $\frac{5}{16}$, and $\frac{7}{16}$ will need to be changed by some undetermined amount, but so that the extremes well be farther apart, and the differences between successive members greater. If $\frac{3}{4}$ of the drift carried from 1, were deposited on 2, 3, and 4, and $\frac{1}{2}$ of that from 2 on 3 and 4, and $\frac{1}{4}$ of that from 3 on 4, the last member of the preceding series of fractions would be increased at the

expense of others. The preceding series would then be brought to some such terms as the following:

From formation 1 - - - - - $\frac{1}{64} = 1\frac{1}{2}\% +$
From formation 2 - - - $\frac{4}{64} = 6\% +$
From formation 3 - - - - - $\frac{15}{64} = 23\% +$
From formation 4 - - - - $\frac{44}{64} = 69\% +$

Thus the constant tendency of the drift to lodge, after being once started, tends still further to diminish the quantity of drift from any formation after the formation is passed.

The effectiveness of the tendency to lodgment of drift near its source is dependent on several conditions. One of them is the rate and steadiness of movement, and another the topography of the surface. The edge of the ice is not believed to have moved forward at equal rates, either during its advance or during its retreat. Whenever the edge of the ice, after a given advance, remained approximately constant in position for a period of years, all the drift brought to the edge of the ice during the halt accumulates beneath it. It presently accumulates in sufficient quantity to form a submarginal ridge or barrier, and when the ice is again affected by movement sufficient to carry its edge farther forward, it is obliged to override or carry forward this submarginal accumulation. Judging from the phenomena of North Greenland, such material was more largely overriden than urged along. Thus the drift gathered toward the center of the ice field is lodged in exceptional quantity wherever the edge of the ice was for a time nearly stationary, and the ice which passed on over the drift which was lodged proceeded to gather a new load made up chiefly of material derived from the surface outside the position of the preceding halt. This tends to emphasize the local facies of the drift.

These considerations in themselves would be quite sufficient, as the last set of fractions shows, to explain the great predominance of relatively local material in the drift of any given region, but other factors serve to emphasize the point still further.

The top of the ice-sheet moves forward faster than the bottom. One reason for this is that the lower part, which is more

fully charged with débris, becomes more rigid, while the more mobile part above moves on over it. If in Fig. 2 the several curves *a*, *b*, *c*, *d* represent the profiles of the ice in successive stages of advance, the ice which is at the bottom, and which is eroding formation 4, may not be the ice which was at the bottom over 2, but instead ice which was well up from the bottom over this formation. In this case it is clear that the ice working on 4 has relatively little material derived from 2. At first thought it might seem that it should have nothing, but this conclusion does not follow. As the relatively débris-free ice above moves

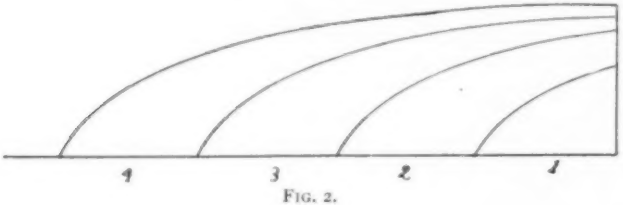

FIG. 2.

over the relatively heavily débris-charged ice below, it drags along some of the material lying in the upper part of the débris zone. Thus as the ice moves over 4, the upper part, being in faster motion, will be carrying along some of that derived from 2 and and even from 1, so that at least a small amount of the material from these formations is to be expected in the bottom of the ice over 4. Nevertheless, the tendency is all along to leave the material already carried by the ice in the rear, and to let the advancing edge acquire its own load, primarily from the successive formations invaded. The result of differential movement, the faster movement being above, is to diminish still further the proportion of the material in the drift at any given point which was derived from distant sources. Because of the effects of differential movement therefore, the last series of fractions would need to be still further changed, so that the first member would be smaller and the last larger.

The topography over which the ice had moved would also influence the proportions of material of near and distant origin.

If the ice passing over 2 encounters a rough topography, so that drift was introduced into the ice far above its base, a large amount of matter from 2 would go forward in the more rapidly moving upper part, and be found in the ice, and finally in the drift, over 4, or beyond.

There is at least one other factor involved. Much of the ice which passes over 4 (Fig. 2) never passed over 1, but accumulated on 2, 3, and 4. This does not preclude the passage of some ice from 1 to 4, but simply means that much of the ice at 4 has never had a chance to work on 1. The idea involved may be gathered from Fig. 3. Let the lines *a*, *b*, and

FIG. 3.

c, respectively, represent the successive profiles of a growing ice-sheet. Much of the upper part of the ice, the profile, of which is *c*, accumulated over areas 2 and 3 and did not come from 1, as already stated. This upper ice which never worked on 1, is moving more rapidly than the ice at lower levels which came in part from 1. Furthermore the conditions of snowfall and movement are such as to develop a high marginal and a low central gradient. The excessive marginal snowfall, for such was probably the condition, will in some sense check movement from the center, and make the marginal portion of the field the effective dynamic center of movement. The origin of much of the ice far from the center of the ice-sheet, where it had no chance to work on rock formations near the center, tended still further to make the material carried and deposited by the ice at any point of local origin. The effect of this factor is to still further differentiate the fractions of the preceding series.

When the spread of the ice, the constant tendency to lodgment of drift in transit, the differential movement, and the marginal origin of much of the ice are all considered, it is probably true that the fractions given on pp. 428, 429 give much

too large a percentage of widely transported material in the drift occupying such a position as that to which the fractions are applied. Taken together, too, these factors would seem to explain adequately the local character of the material of the till.

R. D. S.

SUMMARIES OF CURRENT NORTH AMERICAN PRE-CAMBRIAN LITERATURE.

(*Continued from p. 425, Vol. VII.*)

WALCOTT[1] discusses pre-Cambrian fossiliferous formations of North America. In two cases only have fossils of undoubted organic origin been shown to occur in formations of reasonably certain pre-Cambrian age, namely, the Grand Canyon of Arizona, and the Belt terrane of Montana. The Etcheminian terrane of New Brunswick and Newfoundland is doubtfully a third instance.

A brief account is given of the stratigraphy of each of the areas of pre-Cambrian sedimentary rocks. No new points appear except in the description of the Belt terrane of Montana; the account of the Belt terrane is therefore the only one summarized with reference to stratigraphy.

The Belt terrane of Montana covers an area of more than 6000 square miles in central Montana. The principal beds of the terrane are as follows:

Marsh shales	300 feet.
Helena limestone	2,400 "
Empire shales	600 "
Spokane shales	1,500 "
Greyson shales	3,000 "
Newland limestone	2,000 "
Chamberlin shales	1,500 "
Neihart quartzite and sandstone	700 "
	12,000 feet.

Throughout the area the Belt terrane is overlain unconformably by middle Cambrian rocks (Flathead). The Cambrian rocks rest on various members of the Belt series, and in places the Belt terrane is entirely wanting, the Cambrian resting directly on the Archean schists. In such cases, moreover, the character of the Belt beds indicates that the Cambrian overlaps the Belt series. The base of the Cambrian is not markedly conglomeratic. At most of the outcrops where the lower

[1] Pre-Cambrian Fossiliferous Formations, by CHARLES D. WALCOTT: Bull. Geol. Soc. Am., Vol. X, 1899, pp. 199–244.

beds of the Flathead (Cambrian) sandstone come in contact with the Belt rocks the dip and strike of the two are usually conformable, so far as can be determined by measurement. This holds good all around the great Belt Mountain uplift. It is only when contacts are examined in detail, as near Helena, that the minor unconformities are discovered, and only when comparisons are made between sections at some distance from one another that the extent of the unconformity becomes apparent. In general from 3000 to 4000 feet of the upper strata of the Belt terrane were removed by erosion in late Algonkian time before the Middle Cambrian was deposited. It is believed that an unconformity of this extent is sufficient to explain the absence of Lower Cambrian rocks and fossils and to warrant the placing of the Belt terrane in the Algonkian system.

The fossils thus far found in the Belt terrane occur in the Greyson shales at a horizon approximately 7700 feet beneath the summit of the Belt terrane at its maximum development. The fauna includes four species of annelid trails and a variety that appears to have been made by a minute mollusk or crustacean. There also occur in the same shales thousands of fragments of one or more genera of crustaceans.

Grand Canyon series.—The fossils of the Grand Canyon Upper Cambrian series consist of specimens of a small discinoid shell found in the upper division of the Chuar terrane, and a Stromatopora-like form from the upper portion of the lower division and the central portion of the upper division of the Chuar. Other obscure forms appear whose identification is doubtful.

In New Brunswick certain rocks below the middle Cambrian, according to Matthew, contain fossils which may be pre-Cambrian. (See summary of Matthew's articles, following, p. 435, and of later article by Walcott, p. 436.)

The Llano series of Texas is a series of alternating sandy shales, sandstone, and limestone, very similar to those of the Grand Canyon pre-Cambrian series and overlain by a middle Cambrian sandstone similar to the Tonto sandstone of the Grand Canyon district. No fossils have been found in these rocks, although no systematic search has been made.

The Avalon series of Newfoundland includes all the pre-Cambrian sedimentary rocks of that area. Overlying them are Cambrian strata carrying olenellus fauna.

The Aspidella of the Momable slates is probably of organic origin, but it may be questioned. Other reported forms are inaccessible for study.

In the Lake Superior country markings have been reported as found in the Huronian iron formation of the Menominee iron district of Michigan. An examination of the specimens indicates that they probably are from the basal detrital material of the Cambrian which rests upon the Huronian iron formation. In the Animikie rocks of the Lake Superior region the evidence of life consists of the presence of graphitic material in the slates and of a supposed fossil mentioned by Mr. G. F. Matthew. In the Minnesota quartzite of the Upper Huronian series lingula-like forms and an obscure trilobitic-looking impression are described by Winchell. The latter has been examined and the conclusion is reached that it is of inorganic origin. As to the lingula forms, the weight of evidence is in favor of their being small flattened concretions.

In general, the reported discoveries of fossils in the crystalline rocks of the Algonkian are as yet too problematic to be of value to the geologist and paleontologist. Apparently the best that can be said of Eozoon and allied forms is that they may be of organic origin, but it is not yet proved. The same appears to be true of the supposed fossil sponges described by Mr. G. F. Matthew from the Laurentian rocks of New Brunswick. The graphite in pre-Cambrian forms is probably in many cases of organic origin, but of the character of the life we know nothing.

Palaeotrochis formerly referred to as a pre-Paleozoic coral is determined by Professor J. A. Holmes and J. S. Diller as of inorganic origin.

Matthew[1] describes a Paleozoic terrane beneath the Cambrian in St. Johns and Kings counties, New Brunswick, on Cape Breton, and near Smith Sound, Newfoundland. This terrane is unconformably below Cambrian strata bearing paradoxides and protolenus fauna, and is given the name *Etcheminian*. The faunal features as distinguished

[1] A Paleozoic Terrane Beneath the Cambrian: Annals N. Y. Acad. Sci., Vol. XII, No. 2, 1899, pp. 41–56.

Preliminary Notice of the Etcheminian Fauna of Newfoundland: Bull. Nat. Hist. Soc., New Brunswick, XVIII, Vol. IV, 1899, pp. 189–197.

Preliminary Notice of the Etcheminian Fauna of Cape Breton: Bull. Nat. Hist. Soc., New Brunswick, XVIII, Vol. IV, 1899, pp. 198–208.

The Etcheminian Fauna of Smith Sound, Newfoundland: Trans. Roy. Soc. of Canada, 2d ser., 1899, Vol. V, sec. 4, pp. 97–119.

from the Cambrian are the great preponderance of tube worms, absence or rarity of trilobites, minuteness of the gasteropods, except Patellidae, minuteness of the brachiopods, and the minuteness of the crustaceans.

Walcott[1] believes the *Etcheminian* terrane of New Brunswick and Newfoundland called pre-Cambrian by Matthew to be of Lower Cambrian age. His evidence is:

1. That the Olenellus fauna in Newfoundland occurs 420 feet beneath the Paradoxides fauna, in the heart of the Lower Cambrian "Etcheminian."

2. That fragments of the fauna are found 460–480 feet below the Protolenus fauna in the "Etcheminian" of the Hanford Brook section of New Brunswick.

3. That in the undisturbed, unbroken Highland Range section of Nevada the Olenellus fauna is 4450 feet below the Upper Cambrian fauna, and that the Olenoides (Dorypyge fauna of Matthew) is 3000 feet below the horizon of the Upper Cambrian fauna and 1450 feet above the horizon of the *Olenellus gilberti* fauna.

4. That in the southern Appalachians the Olenellus fauna occurs more than 7000 feet below the highest Cambrian fauna known in that region, and fully 2000 feet below a typical Olenoides fauna.

Matthew[2] makes rejoinder to Mr. Walcott's discussion of the age of the Etcheminian terrane. He argues that Mr. Walcott depends chiefly upon the presence of Coleoloides typicalis as showing the presence of the Olenellus fauna; that this form is not always distinguishable from Hyolithellus micans, a problematical fossil probably of the tube worms, which, with the brachiopods, is the most striking of the fossils of the lower (Etcheminian) terrane. Moreover, the particular form of Olenellus which Mr. Walcott has found is the Olenellus bröggeri, rather than the Olenellus thompsoni, the original Olenellus. Olenellus thompsoni is supposed to occur above the Olenellus bröggeri, yet the Protolenus and Paradoxides faunas follow in regular succession to the fauna of the Olenellus bröggeri. The question is asked: Where is the fauna of Olenellus thompsoni? Its absence is supposedly taken as evidence of the presence of the unconformity held by Matthew.

[1] Lower Cambrian Terrane in the Atlantic Province, by C. D. WALCOTT: Proc. Washington Acad. Sci., Vol. I, 1899, pp. 301–339.

[2] Mr. Walcott's View of the Etcheminian, by G. F. MATTHEW: Am. Geol., Vol. XXV, 1900, pp. 255–258.

Emerson[1] describes the Algonkian rocks occurring in the southwestern corner of the Holyoke quadrangle in Massachusetts and in the area to the west. These are gneisses and limestones making up a series called the Washington gneiss. They are of sedimentary origin with the possible exception of the hornblende-gneiss of East Lee.

In general in western Massachusetts the Washington gneiss appears in oval areas surrounded by younger strata, the line of these ovals extending south from the Hoosac Tunnel along the crest of the Green Mountain plateau. The gneiss enters the Holyoke quadrangle at the southwest corner and runs up across the town of Tolland, narrowing to a point near Black Pond.

Woodworth[2] describes the Algonkian rocks in the lower portion of the Blackstone Valley and west of Providence, R. I., near the western margin of the Narragansett basin. From the typical development of the Algonkian rocks along the Blackstone River between Woonsocket and Pautucket, they are called the Blackstone series. This series is divided into the Cumberland quartzites; the Ashton schists, representing the finer sediments succeeding the deposition and partial erosion of the Cumberland quartzites, and in part probably igneous in origin; and the Smithfield limestone, apparently of sedimentary origin. As yet no facts have been discovered to show whether the limestones are of the same age or newer than the Ashton schists. The rocks of the Blackstone series are separated and penetrated by granitic intrusions or batholites.

The Blackstone series is assigned to the Algonkian because of the difference in metamorphism of the Blackstone series and Lower Cambrian strata, bearing Olenellus fauna, in North Attleboro. The Cambrian strata are little altered and lie in close proximity to the granite. Four miles west the Blackstone series is infolded with a similar granite and much altered.

Kemp[3] gives a petrographical account of the granites of the

[1] B. K. EMERSON: Geology of Old Hampshire County, Massachusetts, comprising Franklin, Hampshire, and Hampden Counties: Mon. U. S. Geol. Surv., No. 29, 1898, pp. 19–30. With geological map. This covers the area of the Holyoke quadrangle and in addition a narrow area to the north and east.

Holyoke folio, Massachusetts-Connecticut: Geol. Atlas of the U. S., No. 50, 1898.

[2] Geology of the Narragansett Basin, Part 2, by J. B. WOODWORTH: Mon. U. S. Geol. Surv., No. 33, 1899, pp. 104–118. With geological map.

[3] Granites of Southern Rhode Island and Connecticut, with Observations on Atlantic Coast Granites in General, by J. F. KEMP: Bull. Geol. Soc. Am., Vol. X, 1899, pp. 361–382; with plates.

Atlantic coast of pre-Cambrian and later age. He finds a striking predominance of biotite granites and gneisses.

Kemp,[1] in connection with a description of the magnetite deposits of the Adirondacks of New York, publishes a geological map of portions of Elizabethtown and Westport townships in Essex county, showing the distribution of the pre-Cambrian magnetite-bearing gabbros, the gneisses, and the limestones. No point in addition to those given in previous reports appears.

Merrill[2] gives a brief summary account of the geological formations of New York, including the pre-Cambrian of the Adirondack area and of the southeastern part of the state. Accompanying the report is a relief map showing the outlines of the geological formations.

Cushing[3] describes an augite-syenite-gneiss near Loon Lake in the Adirondacks. It is nearly related to the anorthosites in age, inasmuch as it is intrusive in the Grenville series, but it is much older than the pre-Potsdam diabases of the region. A study of the relations of the syenites and anorthosites indicates that the syenites are in part a result of differentiation in the anorthosite magma after reaching its place of final cooling, and in part are somewhat later in date.[4]

Smyth[5] summarizes his ideas to date on the geology of the Adirondacks. Gneisses, limestone, and gabbro are the principal rocks. From studies in the western Adirondacks it is certain that some of the gneisses are of igneous origin, being granites syenites, gabbros, etc., which have been modified by metamorphism; while others, with equal certainty, are altered sediments. But by far the larger part of the gneisses have as yet received no careful study. The limestones are certainly sedimentary. Their relations to the gneisses are in doubt, but some parts of the gneisses are certainly younger than the limestones,

[1] The Titaniferous Iron Ores of the Adirondacks, by J. F. KEMP: Nineteenth Ann. Rept. U. S. Geol. Surv., 1897–8, Part 3, 1899, pp. 377–422. With geological map.

[2] A Guide to the Study of the Collections of the New York State Museum, by F. J. H. MERRILL: Bull. N. Y. State Museum, Vol. IV, No. 19, 1898, pp. 109–262; with geological map.

[3] Augite-Syenite-Gneiss near Loon Lake, New York, by H. P. CUSHING: Bull. Geol. Soc. of Am., Vol. X, 1899, pp. 177–192.

[4] The anorthosites are a part of the great gabbro mass which forms the core of the Adirondacks intruding pre-Cambrian sedimentary and igneous gneisses.

[5] Geology of the Adirondack Region, by C. H. SMYTH, JR.: Appalachia, Vol. IX, No. 1, May 1899.

and this may be true of all. The gabbro breaks through both gneisses and limestones. It presents two phases, an anorthosite, and a gabbro containing abundant pyroxene and other ferro-magnesian minerals. In places also in the western Adirondacks the granites and syenites break through the limestone.

Barlow[1] gives a further account of the results of work being carried on by himself and Dr. Adams in the counties of Hastings, Haliburton, and Renfrew, Province of Ontario. Many of the so-called conglomerates of the Hastings and Grenville series are believed to be autoclastic rocks or pseudoconglomerates which have resulted in the main from complex folding and stretching. Therefore such rocks cannot be cited as evidence of the clastic origin of the Hastings and Grenville series, as has been done.

Barlow[2] describes the geology of the Nipissing-Temiscaming map-sheets, comprising portions of the district of Nipissing, Ontario, and the county of Pontiac, Quebec.

Laurentian and Huronian rocks occupy most of the area. These do not include a few small isolated inliers of crystalline limestone and gneissic rocks which resemble the Grenville rocks to the south and southwest. These are so small in quantity that they are not mapped. Their relations to the Huronian are not discussed.

The Laurentian rocks occupy the two thirds of the area of the two sheets. While probably representing in part the first formed crust of the earth, and therefore the basement upon which the Huronian rocks were laid down, the Laurentian has undergone successive fusions and recementations before reaching its present condition. It is now a complex of plutonic rocks which in general show irruptive relations to the overlying Huronian series. However, on Lake Temiscaming the Laurentian is unconformably below, and in direct contact with, an arkose of Huronian age, which has apparently been derived from the disintegration the Laurentian granite.

The Huronian occupies about a third of the combined area of the two sheets. It is separable into three divisions, in ascending order as

[1] On the Origin of some Archean Conglomerates, by A. E. BARLOW: The Ottawa Naturalist, Vol. XII, 1899, pp. 205–217. See Am. Journ. Sci., 4th series, Vol. III, 1897, pp. 173–180.

[2] Geology and Natural Resources of the Area included by the Nipissing-Temiscaming Map-sheets, comprising Portions of the District of Nipissing, Ontario, and of the County of Pontiac, Quebec, by A. E. Barlow: Ann. Report Geol. Surv. of Canada, Vol. X, Pt. 1, 1899, pp. 302. With geological map.

follows: (1) breccia or breccia-conglomerate, (2) graywacke shale or slate, and (3) feldspathic sandstone or quartzite. The maximum thickness of the first division is 600 feet; of the second, 100 feet; and of the third, 1100 feet. Associated with these clastic rocks are various rocks of igneous origin, including deep-seated diabase and gabbro and volcanic ejectamenta.

Comments.—The nature of the relations of the Huronian and Laurentian rocks has so long been a subject of controversy and the ground has been gone over so many times that comment seems unnecessary. But for readers who have not followed the controversy a statement of one of the main points of contention may be of service. The Laurentian rocks of Barlow and other Canadian geologists form the basement upon which the Huronian rocks were deposited, and they also have intrusive relations to the Huronian rocks. This anomaly is explained by the fact that the granites and gneisses really form the basement upon which the Huronian rocks were deposited, but that since this deposition the granites and gneisses have been softened by fusion, perhaps due to the weight of the overlying rocks, and that they now invade the lower portions of the Huronian rocks.

Other geologists, particularly the United States geologists, have maintained that no evidence has been adduced to show that there has been any softening of the basement granites near their contact with the overlying Huronian sediments; that the granites and gneisses included under the Laurentian by the Canadian geologists are of widely different ages; that they comprise both the original basement rocks, in their original form, upon which the Huronian was deposited, and later rocks, intrusive into both the Laurentian and Huronian; and furthermore, that in most regions it will be possible by close areal mapping to distinguish these different granites and gneisses. They would map the basement granites and gneisses as one series, and separate from them all later intrusives.

Although Mr. Barlow has for many years maintained the total absence of the normal erosion unconformity between the Laurentian granite and the Huronian, he now reports the "discovery" of such a contact near Lake Temiscaming. In finding a normal erosion unconformity in this area he is many years behind Pumpelly, Irving, and Van Hise, as indicated in a comment on a previous article of Mr. Barlow.[1] It is thus now agreed that the original basement granites and

[1] JOUR. GEOL., Vol. II, p. 419.

gneisses are present in this area. Mr. Barlow cites no evidence to show that softening of the granites and gneisses has anywhere occurred immediately subjacent to the sediments, resulting in the invasion of the sediments by the granites and gneisses; that any eruptive relations now found are not those of the normal intrusion of granite magmas into both the original basement and the overlying sediments.

Ells[1] gives an historical account of the geological nomenclature of that part of Canada which extends roughly from the Red River of Manitoba eastward over Canada. The present usage with reference to pre-Cambrian rocks may only be mentioned.

In Nova Scotia the term pre-Cambrian has been given to certain old crystalline rocks which were found to underlie the recognized Cambrian of the coast or of the gold-series, and which were found to strongly resemble certain portions of the Laurentian or Huronian of the western provinces.

In New Brunswick there has been little change in the nomenclature proposed by Matthew, Bailey, and Hunt. The lowest division of the crystalline rocks was held to conform most closely in its details to the Laurentian of the Canadian Survey. This series was divided into a lower and an upper division, the former of which was regarded as the equivalent of the Lower or Fundamental Gneiss of the Ottawa district, while the latter was supposed to represent the limestone and gneiss of the Grenville series of Quebec. The Huronian was made to include three divisions, viz., the Colebrook, the Kingston, and the Coastal. Since this time Matthew has introduced the term Etcheminian to designate certain fossiliferous sediments found beneath the middle Cambrian, probably belonging to the more recent portion of the pre-Cambrian formations.

In Ontario and Quebec the oldest granite-gneiss may be styled Laurentian. The second member of the scale, or the Huronian, may be made to include, as its lowest portion, that part of the crystalline series, once regarded also as part of the Laurentian system, and known locally under the names Grenville and Hastings series, the relations of which to the Laurentian proper are apparently of two kinds, either a stratigraphical sequence, with a probable unconformity, owing to their difference in origin; or a contact of intrusion; and that portions of the Grenville and Hastings series correspond, while the latter is carried

[1] Canadian Geological Nomenclature, by R. W. ELLS: Trans. Royal Soc. of Canada, 2d series, Vol. V, sec. IV, 1899, pp. 3–38.

upward through less altered sediments to the upper members of the Huronian system.

In the Lake Superior region the Huronian is succeeded upward by the rocks of the Cambrian, represented by the Upper Copper-bearing series, or the Animikie and Nipigon groups; while in eastern Ontario this portion of the scale is apparently entirely lacking, the formation succeeding the crystalline series being the Potsdam sandstone, which is now held to represent the lowest number of the Cambro-Silurian or Ordovician system.

Comment.— Adequate discussion of the above scheme of nomenclature is quite impossible in the space available. It may be said only that the scheme will be dissented from on many important points by many of the United States geologists.

Crosby[1] describes the Archean-Cambrian contact near Manitou, Col. A sandstone of Cambrian age rests upon an Archean granite complex. The granite floor has very small erosion inequalities. These inequalities are hummocks, not hollows; erosion remnants, and not channels; clearly marking the end, and not the beginning of a process of base-leveling.

It is believed that such an even contact plane between the Cambrian and pre-Cambrian series is widespread and characteristic in North America. It appears to be the case in the valley of the Eagle River and in the canyon of the Grand River above Glenwood, Col.; in the Black Hills of South Dakota, examined by the writer; in the Grand Canyon of the Colorado, described by Walcott; and in Wisconsin, described by Irving.

In the Manitou, Eagle River, and Black Hills areas, throughout the Rocky Mountains, and eastward to Champlain Valley and beyond, the Cambrian has a non-arkose character; it has been thoroughly sorted and washed by water, a fact which indicates that the incursion of the sea was an extremely slow one. It is believed that the plane surface of the Archean has resulted from the incursion of the sea due to the subsidence of the land, and not from the action of subaerial agents, for in the latter case only an approximate plane could have resulted because of differential erosion.

Emmons[2] describes the Archean rocks of the Ten-mile quadrangle of Colorado. These rocks outcrop to the east of the great fault — the

[1] Archean-Cambrian Contact near Manitou, Col., by W. O. CROSBY: Bull. Geol. Soc. Am., Vol. X, 1899, pp. 141–164.

[2] Ten-mile District Special Folio, Colorado, by S. F. EMMONS: Geol. Atlas of the U. S., No. 48, 1898.

Mosquito fault — running north of Leadville. They consist of granites, granite-gneisses, mica-schists, and amphibolites, with pegmatite veins traversing them in every direction. Gneisses and schists are the prevailing types.

A small patch of Cambrian sediment is found resting unconformably on the Archean to the east of the Mosquito fault.

Hague[1] describes the Archean rocks of the area covered by the Absaroka folio in the northwestern part of the state of Wyoming. These consist of crystalline-schists and gneisses, mainly mica-gneiss, amphibolites, and schists distinctly light colored, which are found only in the northeastern part of the Crandall quadrangle.

Sedimentary rocks of middle Cambrian age overlie the Archean rocks unconformably.

Irving[2] gives a detailed description of the geology of an area in the northern Black Hills of South Dakota. The Algonkian rocks consist of quartzites, slates, phyllites, and schists, all of sedimentary origin. No new point is added concerning the stratigraphy of the pre-Cambrian rocks.

C. K. LEITH.

[1] Absaroka Folio, Wyoming, by ARNOLD HAGUE: Geol. Atlas of the U. S., No. 52, 1899.

[2] A Contribution to the Geology of the Northern Black Hills, by JOHN DUER IRVING: Annals N. Y. Acad. Sci., Vol. XII, 1899, Pt. 9, pp. 187–340.

STUDIES FOR STUDENTS

THE EOCENE OF NORTH AMERICA WEST OF THE 100TH MERIDIAN (GREENWICH).[1]

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[1] The following essay is the outcome of a topical study undertaken by the writer as a student at the University of Chicago. While it is based entirely on the literature of the subject, it brings together so many scattered data concerning a series of formations which often seem intangible to the student, that it is printed in the belief that the summation may be serviceable to students who wish to get information beyond that of text-books, and who have not access to the original reports.—[ED.]

THE Eocene deposits of western North America may be divided into three groups, namely, those laid down in fresh water, those laid down in brackish water, and those laid down in sea water. To these should probably be added those deposited by streams, though this class of formation has not been generally differentiated from the first.

1. *The fresh-water deposits* stretch with many interruptions from New Mexico and Colorado northward and nothwestward through Utah, Wyoming, Montana, North Dakota, the Dominion of Canada, to the Arctic Circle and probably the Arctic Ocean. The formations belonging to this area are the Fort Union, which is the Upper Laramie of the Canadian Geological Survey, the Kenai, Puerco, Torrejon, Wasatch, Bridger, including Green River, Uinta, Huerfano, Mojave, Amyzon, and Manti. In addition there are non-fossiliferous conglomerates which are supposed to be of Eocene age, as follows: Sphinx conglomerate, Pinyon conglomerate, and San Miguel conglomerate.

2. *The brackish-water deposits* extend with interruptions from Oregon through Washington into British Columbia. The formations belonging to this group are Arago and Puget.

3. *The marine deposits* in Oregon and California. The formations belonging to this group are Tyee, Umpqua, Martinez, and Tejon.

In the following pages the known data concerning the distribution and nature of these several formations is summarized, and their correlation as determined by various investigators indicated.

THE FRESH-WATER BEDS.

THE FORT UNION FORMATION.

The Fort Union beds are named from a former military fort on the Missouri River in North Dakota where they are typically exposed. They occur in North Dakota, Montana, extending thence north and northwest into Canada and with interruptions to the Arctic Circle and probably to the Arctic Sea. These beds are thus described by Meek and Hayden[1]: "Beds of clay

[1] Quoted by Clark, U. S. Geol. Surv., Bull. 83, p. 113, 1891.

and sand with round ferruginous concretions and numerous beds, seams, and local deposits of lignite; great numbers of dicotyledonous leaves, stems, etc." Under the name *Paskapoo*, Tyrrell describes this formation as being at least 5700 feet in thickness[1]: "The beds consist of more or less hard, light gray or yellowish-brownish weathering sandstone, usually thick-bedded, but often showing false bedding; also of light bluish-gray and olive sandy shales, often interstratified with bands of hard lamellar ferruginous sandstone, and sometimes with bands of concretionary blue limestone, which burns into an excellent lime. The sandstones consist of very irregular, though slightly rounded, grains of quartz, felspar, and mica, cemented together in a calcareo-argillaceous matrix."[2] Its fauna shows that this entire series is of fresh-water origin.

Because of the nature of the stratigraphy of the rocks of this region, and because of the fact that dinosaurs became extinct immediately before the Paskapoo epoch, because a time of great disturbance "in which the Rocky Mountains were uplifted" preceded the Paskapoo, Tyrrell thinks this break between the Cretaceous and Paskapoo marks the close of the Cretaceous, "and that the Tertiary epoch began with the commencement of the Paskapoo period, during which a great thickness of sandstones and sandy shales was laid down without any apparent break or unconformity. In this Paskapoo series, then, we have the representative of the Eocene of Europe."[3]

Weed, writing of the Crazy Mountains of Montana, says[4]: "These mountains are formed of Livingston beds, conformably overlain by a series of sandstones and clay shales, characterized by fresh-water fauna, and lithologically distinct and readily differentiated from the somber-colored sandstones of volcanic material composing the Livingston beds. The plant remains of these [upper] beds are not of Laramie nor of Denver bed types, but are species characteristic of the strata in the vicinity of Fort

[1] Geol. and Nat. Hist. Surv. of Canada, Ann. Rep. n. s., Vol. II, p. 135 E. 1886.

[2] TYRRELL: loc. cit., p. 136. [3] Loc. cit., p. 138.

[4] Amer. Geol., Vol. XVIII, pp. 204, 205, 1896.

Union, and that name is therefore adopted for the formation." A section is given showing Fort Union beds to be 4648 feet thick at this place. "The importance of this section, which is the only one known to the writer in which the Fox Hills, Laramie, Livingston, and Fort Union formations occur superimposed, is apparent when it is considered that in eastern Montana and Canada the Fort Union rests directly upon Laramie beds in apparently perfect conformity."[1] Vertebrate fossils were not found, but the invertebrate fossils from the Fort Union beds at this place were submitted to Stanton, who reported that "almost all the species of the list were originally obtained near Fort Union on the Missouri River."[2]

Of Fort Union fossils in the United States National Museum, Weed says[3]: "They have been studied by Professor Knowlton, who reports that the Fort Union flora embraces 169 species. Of this number 130 species are confined to this formation. Of the 39 species found in other terranes, 21 occur in the Miocene, 14 in the Denver (post-Laramie), and 9 in the Laramie. These figures tell their own story." Knowlton states that the flora as a whole is clearly Eocene. This confirms the statement of Newberry that the floras of the Laramie and the Fort Union are totally distinct, "and that these formations should be referred to different geological horizons, the Fort Union to the Tertiary, and the Laramie to the Cretaceous." Weed gives the following table showing "the comparative sections found along the Rocky Mountain front."[4]

Age	Montana	Canada	Colorado
Eocene	Fort Union	Paskapoo (570c') { Porcupine Hills / Willow Creek	
Post Laramie	Livingston	(Erosion interval)	*b.* Denver beds *a.* Arapahoe beds
	Unconformity		Unconformity
Cretaceous	Laramie	Edmonton (Tyrrell) or Wapiti River (Dawson)	Laramie

[1] WEED: loc. cit., p. 206.
[2] Quoted by Weed, loc. cit., pp. 206, 207.
[3] WEED: loc. cit., p. 210.
[4] Loc. cit., p. 211.

This conclusion concerning the age of the Fort Union formation has been supported by the Dawsons, as shown by the following: "Dr. G. [M.] Dawson and the writer [Sir William Dawson] have, ever since 1875, maintained the lower Eocene age of our [Canadian] Laramie, and of the Fort Union group of the northwestern United States. . . . ."[1]

THE PUERCO FORMATION.

The Puerco formation is located in northwestern New Mexico at the headwaters of Puerco River, from which the formation takes its name, and where it "reaches a thickness of outcrop of about 850 feet."[2] The rocks of this formation consist of "sandstones and gray and green marls."[3] The formation is thus characterized by Wortman:[4] "The thickness of the beds is roughly estimated at 800 to 1000 feet, and as far as can be observed they lie conformably upon the Laramie."

The fossils occur at two horizons which are separated by barren strata 700 to 800 feet thick (not 30 feet as erroneously quoted by Dall in the Eighteenth Annual Report U. S. Geol. Surv., Part II, p. 347). "The lower fossil-bearing strata occur in two layers, the lowermost of which lies within 10 or 15 feet of the base of the formation. This is succeeded after an interval of about 30 feet by a second stratum in which fossils are found. . . . . Both of these strata are red clay, and at no place did we find them more than a few feet in thickness."[5]

This horizon "is especially and sharply distinguished by the occurrence of the remains of Polymastodon, which appear to be entirely absent from the upper horizon."[6] The upper horizon is richer in fossils than the lower. "The genera Chirox and Pantolambda appear to belong exclusively to the upper beds."[7]

[1] Quoted by Knowlton, Bull. V, Geol. Soc. Amer., p. 589, 1894.

[2] CLARK: U. S. Geol. Surv., Bull. No. 83, p. 138, 1891.

[3] CLARK: loc. cit., p. 138.

[4] Quoted by Osborn, Bull. Amer. Mus. Nat. Hist., Vol. VII, p. 1, 1895.

[5] WORTMAN: quoted by Osborn, loc. cit., p. 2.

[6] *Ibid.* [7] *Ibid.*

Wortman believes that the upper fossiliferous horizon contains several layers, and that their vertical range is somewhat greater than that of the lower horizon." Matthew states that the "Upper and Lower Puerco beds do not contain a single species in common, and only three or four genera pass through. The two faunas are entirely distinct. Dr. Wortman proposes to call the upper beds the Torrejon formation, retaining the name Puerco for the lower beds."[1] Scott correlates the Puerco with the Cernaysien of Europe.[2]

THE WASATCH FORMATION.

The Wasatch formation occurs in a large area in Utah, Wyoming, and Colorado. It is equivalent to the Vermillion Creek of King; Bitter Creek of Powell; and Coryphodon beds of Marsh. The fossils indicate that the rocks were deposited in fresh water. "From the outcrops thus broadly sketched it is clear that a single lake extended from longitude 106° 30′ to 112°, stretching northward probably over the greater part of the Green River Basin, and southward to an unknown distance."[3]

The Wasatch beds lie upon the Cretaceous with a discrepancy in dip, as shown by King, of 0° to 25° in many places. Clark says:[4] "The Wasatch strata throughout much of their extent are conformable to the Laramie, but in western Wyoming and eastern Utah a marked unconformity is exhibited." King thus describes the Wasatch formation, which he names Vermillion Creek:[5] "It is made up of a heavy gritty series at the base, which in the region of Vermillion Creek and north of Evanston is gray, but as displayed at Echo Canyon and East Canyon Creek is characterized by the presence of enough red sandstones and clays to give it more of a brick or in places a deep pinkish color. The middle members are of finer material and are more intercalated with clays, while the upper part of the series has shown wherever the group comes in contact with the Green

[1] Science, n. s., Vol. VII, p. 852, 1897. [2] Science, n. s., Vol. II, p. 499, 1895.
[3] KING: U. S. Explorations of the 40th Parallel, Systematic Geol., Vol. I, p. 374.
[4] Loc. cit., p. 139. [5] Loc. cit., p. 375.

River series, is made up of striped and banded sandstones, varying from gray to yellow, white, and red, with prevailing white and red tints. As regards the relations of this with the underlying group, it should be repeated that the evidence has finally accumulated so that there can be no longer a doubt where to draw the line between the Cretaceous and the Tertiary series. I unhesitatingly say that the bottom of the Vermillion Creek is the base of the Tertiary, and that it rests in essential unconformity (though locally in accidental conformity) upon the Cretaceous."

Scott, in a paper read before the British Association, correlates the Wasatch with the Suessonien of Europe.[1]

THE BRIDGER FORMATIONS (including Green River and Wind River).

The Bridger is divided by Scott[2] into two substages, namely, Wind River substage (=Green River substage), and Bridger substage. The Bridger deposits are less extensive than the Wasatch.[3] The Wind River beds lie chiefly in the valley of Wind River, Wyoming, east of the Wind River Mountains. The width of their outcrop is from one to five miles, and its length about 100 miles. The beds reach a thickness of 1000 feet, and are composed of sandstones and shales.

The Green River beds are in the valley of the Green River in Wyoming, Colorado, and Utah, on the west side of Wind River Mountains. Paleontological evidence shows them to be of essentially the same age as the Wind River beds, hence the appropriateness of this name for both series. Outliers of Green River beds occur west to about longitude 116° W. in Nevada, and King interprets this fact as showing that the waters in which they were deposited were probably bounded by the Piñon Mountains.[4] "The Green River series rests for the most part unconformably upon the horizontal as well as the highly inclined Vermillon Creek [Wasatch] beds."[5] These beds are described

[1] Science, n. s., Vol. II, p. 499, 1895. [2] Introduction to Geology, p. 496, 1897.
[3] SCOTT: loc. cit., p. 499. [4] Loc. cit., p. 393. [5] KING: loc. cit., p. 378.

as "calcareous sands and slightly siliceous limestones, which are overlaid by remarkably fissile shales." The limestones are about 800 feet thick; the shales 1200 feet thick. The beds contain fresh-water fossils but "no brackish-water forms whatever."[1]

The formation of the Bridger substage is described by King[2] as follows: "Throughout the middle of the Bridger Basin it rests in positions of complete horizontality, and throughout its whole extent shows no evidence of orographical disturbance, such as could be registered in local changes of angle. The aggregate thickness of the beds of this group is estimated as between 2200 and 2500 feet. The material is almost wholly made up of fine sand and clay, arranged in varying proportions and occasionally slightly changed by calcareous mixtures." Scott correlates the Bridger with the Parisien of Europe.[3]

THE HUERFANO FORMATION

The Huerfano beds in Huerfano county, Colorado, were first described by R. C. Hills in 1888. He estimated the thickness to be 8000 feet and made three divisions of the beds. In 1891 Hills identified the upper beds, which consist of clays, soft shales and sand, as Bridger, and estimated its thickness at 3300 feet. Below this lie the Cuchara beds 300 feet thick, and below the Cuchara are the Poison Canyon beds 3500 feet thick. The lower two divisions he considered Lower Eocene. In 1897 Osborn and Wortman visited the region and arrived at the following conclusions[4]: (1) "That west of Huerfano Canyon the variegated marls, clays, soft shales and sands aggregate only 800 to 1000 feet in thickness and are nearly horizontal in position. They may be positively divided into upper beds equivalent to the Bridger,[5] and lower beds, equivalent to the Wind River or Upper Wasatch.

[1] KING: loc. cit., p. 389. [2] Loc. cit., p. 400.

[3] Science, n. s., Vol. II, p. 499, 1895.

[4] OSBORN: Bull. Amer. Mus. Nat. Hist., Vol. IX, p. 250, 1897.

[5] "Bridger" and "Wind River" appear to be used in the sense of "Bridger substage" and "Wind River substage" respectively as used by Scott. Cf. SCOTT'S Introduction to Geology, p. 496, table.

These constitute the only true Huerfano deposits. (2) That the Cuchara and Poison Canyon beds are unconformable with the Huerfano beds and older than the Eocene, probably marine cretaceous as partly determined by the presence of a species of *Baculites* in the yellow sandstone of the typical Poison Canyon section. (3) That the present canyon of the Huerfano River cuts through the base of the main anticlinal axis of post-Laramie origin, which formed the eastern boundary of the lake. This axis extended to the south so as to include the base of Silver Mountain toward the Cuchara divide; but it lies from three to seven miles west of the anticlinal axis described by Professor Hills. (4) That the Huerfano lake deposition did not extend as far to the east or south as Spanish Peaks, and that the variegated beds observed there are of older origin. This would materially affect the geological age of the prominent neighboring laccoliths."

From the above conclusions it will be observed that the Huerfano beds are much more restricted geographically than was supposed by Hills. They occupy a part of the basin of the upper part of Huerfano River, between the Wet Mountains on the northeast and the Sangre de Cristo and Culebra ranges on the west and south. Osborn thinks the beds were formed by the damming of the Huerfano River by a post-Laramie axis of uplift which was afterward trenched by the river. The lake was thus drained.

It appears from Osborn's conclusions that the two divisions of the Huerfano beds represent the two substages of the Bridger stage of Scott. The name Huerfano should be restricted to one of these divisions. The other division should receive a new name.

THE UINTA FORMATION (=Brown's Park group of Powell).

The Uinta formation was named by King from the Uinta Mountains, on the flanks of which its outcrops occur. The Uinta is described as follows[1]: ". . . . it is possible that this group was deposited continuously, at least in part, with the Bridger

[1] Quoted by Clark, loc. cit., p. 143.

group, but at the places where the junction between the two groups have been seen in this region there is an evident unconformity, both of displacement and of erosion. The group consists of fine and course sandstones, with frequent layers of gravel, and occasionally both cherty and calcareous layers occur. The sandstones are sometimes firm and regularly bedded, and sometimes soft and partaking of the character of bad land material. The color varies from gray to dull reddish-brown, the former prevailing north of the Uinta Mountains, the latter south of them." King says the lower members of the Uinta group are, "chiefly rough, gritty conglomerates, passing up into finer grained sandstones, and at certain points developing creamy, calcareous beds."[1]

The vertebrate fossils show the Uinta to be a fresh water deposit. Scott notes that a considerable break [physical?] occurs between the Bridger and the Uinta, and that earth movements took place at this time. He makes the Uinta equivalent to the Paris gypsum deposits[2]. Peterson finds the following succession of strata in the Uinta basin.[3] (1) Wasatch; (2) conformably upon Wasatch, Green River; (3) conformably upon Green River, a series of hard, brown sandstones, alternating with greenish-gray clays; (4) conformably upon this are layers of coarse, brown sandstone alternating with shales; (5) "*true Uinta* or Brown's Park beds of a fine grained soft material . . . . of brick-red color." These last named beds are about 600 feet thick. Describing the highest three (3, 4, and 5 above) Peterson says:[4] "This uppermost strata [stratum] of the Uinta basin has hitherto been reported as resting unconformably upon the Bridger sediment, but no observable breaks were found to distinguish the true Uinta from underlying Bridger sediment. So the writer found it necessary in collecting fossils to divide the beds overlying the Green River shales into three different levels, which are here arranged alphabetically in ascending position

[1] Loc. cit., p. 405. [2] Science, n. s., Vol. II, p. 499, 1895.

[3] Quoted by Osborn, Bull. Amer. Mus. Nat. Hist., Vol. VII, p. 73, 1895.

[4] Quoted by Osborn, loc. cit., p. 74.

[A being lowest]: Horizon C, true Uinta beds 600 feet thick, sandstones and clays brownish and reddish, ferruginous . . . . "Horizon B, 300 feet thick. Soft coarse sandstones and clays. Horizon A, 800 feet thick. Hard brown sandstones immediately overlying the Green River shales." Commenting upon the above field notes Osborn says[1]: "These excellent observations supply one of the most important links in the American lake faunal chain, namely that between the Washakie[2] and the Uinta. The explorations of the present year, 1895, may modify these results, but it is certain we have now not only established a complete faunal transition from the Bridger and Washakie beds upon the one side, to the true Uinta level or Horizon C upon the other, but have demonstrated a closer connection between the fauna of this basin and that of the lowest White River Miocene."

THE AMYZON FORMATION

Under this name Cope has described beds in Elko county, Nevada; in South Park, Colorado; and in central Oregon. He regards them as belonging to the "later Eocene or early Miocene eras."[3] King described and mapped the same beds of Nevada as of Green River age.[4]

Cope thus describes the beds of Oregon: "The regions of the John Day River and Blue Mountains, furnish sections of the formations of central Oregon. . . . . Below the Loup Fork follows the Truckee [Neocene] group, so rich in extinct mammalia, and below this a formation of shales. These [shales] are composed of fine material and vary in color, from a white to a pale brown and reddish-brown They contain vegetable remains in excellent preservation, and undeterminable fishes. The *Taxodium* nearly resembles that from the shales at Osino, Nevada, and on various grounds I suspect that these beds form a part of

[1] Loc. cit., pp. 74, 75.

[2] Beds belonging to the upper part of the Bridger substage lying east of Green River in southern Wyoming. Cf. Clark, U. S. Geol. Surv., Bull. No. 83, pp. 117, 142.

[3] Amer. Nat., Vol. XIII, p. 332, 1879.

[4] U. S. Geol. Explorations of the 40th Parallel, Vol. I, Systematic Geol., p. 393, 1878.

the "Amyzon Group" (*American Naturalist*, June 1880), with the shales of Osino and of the South Park of Colorado."[1] The Amyzon beds of Nevada appear in the accompanying map. Those of Colorado and of Oregon are not here mapped.

THE MANTI FORMATION

Cope has described this formation as follows:[2] "There is, however, a series of calcareous and silico-calcareous beds in central Utah, in Sevier and San Pete counties, which contain the remains of different species of vertebrates than those which have been derived from either the Green River or Amyzon beds. These are *Crocodilus*, sp., *Clastes cuneatus* Cope, and a fish provisionally referred to *Priscacara* under the name *P. testudinaria* Cope. There is nothing to determine to which of the Eocenes this formation should be referred, but it is tolerably certain that it is to be distinguished from the Amyzon beds. In its petrographic characters it is most like the Green River, as it consists in large part of shales. The laminae are generally thicker than those of Green and Bear rivers. The genera *Crocodilus* and *Clastes* have not been found heretofore in Green River beds, although they are abundant in the formations deposited before and after that period. Until its proper position can be ascertained, I propose to call the formation the Manti beds."

Some years later Cope regarded these beds as of probably Wind River age. He says, "A probable second locality of this [Wind River] formation is known in eastern Utah, in the Wasatch Mountains. This formation is known as the Manti beds."[3]

THE MOJAVE FORMATION

Fairbanks has described[4] a formation in southeastern California which is probably Eocene. "On the northern slope of the El Paso range, between Mojave and Owen's Lake, there is a series of beds of clays, sandstone, volcanic tuffs, and interbedded

[1] Proc. Amer. Philos, Soc., Vol. XIX, p. 61, 1880.

[2] Amer. Nat., Vol. XIV, pp. 303, 304, 1880.

[3] *Ibid.*, Vol. XXI, p. 454, 1887.

[4] Geology of eastern California, Am. Geol., Vol. XVII, p. 63, 1896.

lava flows. These are probably 1000 feet or more in thickness and extend over a considerable area between the El Paso range and the Sierra Nevadas. . . . . They are finely exposed in Red Rock canyon and about Black Mountain. . . . . The beds are tilted northward at an angle of 15–20 degrees. . . . . Impressions of leaves occur in the clay immediately above the seam of coal. These were submitted to Dr. F. H. Knowlton who says: 'I have looked over the three small fragments of fossil plants from the Mojave desert with the following result: Two species are represented, *Spindus affinis* Newb., and *Anemia subcretacea* (Sap.) Ett. and Gard. . . . . The plants indicate a Tertiary age without doubt, and they seem to belong to the Eocene. Both species have quite a wide distribution geographically and are confined, with several unimportant exceptions, to the Eocene.'"[1]

EOCENE OF BATES HOLE, WYOMING

In the valley of Bates Creek, Natron county, Wyo., fossiliferous Eocene beds occur. They have been but recently recognized and no published account of them is known to the writer.

THE KENAI FORMATION

The coal bearing beds typically seen on Kenai peninsula, Cook Inlet, Alaska, "but widely spread in British Columbia and over the coast of Alaska and its adjacent islands" are called by Dall and Harris the Kenai group.[2] Cretaceous Aucella beds lie beneath the Kenai, but whether marine beds of the same age as Kenai intervene is uncertain.[3] "In Alaska, at Cook's Inlet, at Unga Island, at Atka and at Nulato in the Yukon valley we find the leaf beds of the Kenai group immediately and conformably overlain by marine beds containing fossil shells which are common to the Miocene of Astoria, Oregon, and to middle and southern California."[4] Kenai rocks consist of "great thicknesses of somewhat loosely consolidated conglomerates, sandstones, and shales, all generally greenish in character. They contain everywhere

[1] FAIRBANKS: loc. cit., pp. 67, 68.

[2] DALL and HARRIS, Bull. No. 84 U. S. Geol. Surv., pp. 234 et. seq., 1892.

[3] *Ibid.*, loc. cit., p. 251.

[4] *Ibid*, loc. cit., p. 251.

plant remains and frequent seams of lignite, and rest unconformably upon the older formations."[1]

The conclusion concerning the age of the Kenai is based upon its fossil plants and upon its stratigraphic relations. In 1892 Dall, after a summary of the evidence, concludes that the Kenai "is probably of Eocene age. . . . . "[2] In 1896 Dall says, "When we consider that the Oligocene Aturia bed is immediately and conformably overlain at Astoria, Oregon, by shales and sandstones undoubtedly equivalent to the Alaskan marine Miocene, and that the latter, in like manner, immediately and conformably overlies the Kenai group it must be considered that the view that the latter is Oligocene seems highly probable."[3]

In the following year Dall places the Kenai beds in the Eocene, remarking that, "They are with little doubt coeval with the Atane beds of Greenland and other arctic leaf-bearing strata. Their exact horizon is doubtful, but some of the plants appear to be common to the lignitic beds of the Mexican gulf coast, and they are provisionally placed here awaiting more definite information."[4]

BRACKISH WATER DEPOSITS

THE PUGET FORMATION

The Puget formation occurs in Washington in the Puget Sound basin upon the western flank of the Cascade range, extending to Burrard's Inlet, British Columbia. At Comox and elsewhere in Vancouver Island. On the eastern side of the Cascade Mountains beds occur which are lithologically like the Puget formation and probably belong to it.[5] No fossils have been found in these beds east of the mountains. The Puget formation is thus described by Willis and Smith:[6]

[1] SPURR: Eighteenth Ann. Rep. U. S. Geol. Surv. for 1896–7, Part III, Economic Geology, p. 194.

[2] DALL and HARRIS: loc. cit., p. 252.

[3] DALL: Seventeenth Ann. Rep. U. S. Geol. Surv., 1895–6, Part I, pp. 841, 842.

[4] Eighteenth Ann. Rep. U. S. Geol. Surv., 1896–7, Part II, p. 345.

[5] SIR WILLIAM DAWSON: Trans. Roy. Soc. Can., n. s., Vol. I, pp. 137, 138, 1895.

[6] Geol. Atlas of the U. S., Tacoma Folio, Washington, 1899.

The Puget formation consists of interbedded sandstones, shales and coal beds aggregating 10,000 feet or more in thickness. Sandstones prevail. They are of variable composition, texture, and color, and are frequently cross stratified. Their composition ranges from a typical arkose, consisting of slightly washed granitic minerals to siliceous clays. The separate beds vary from a few inches to more than 100 feet in thickness. Conglomerates and concentrated quartz sands have not been observed. The variations in color are not such as to distinguish upper and lower sections of the formation. In general the strata are similar and are similarly interbedded from top to bottom.

The shales of the Puget formation are formed of siliceous clayey muds containing sometimes considerable carbonate of iron, and generally more or less carbonaceous matter, which varies in character from finely divided organic material to large leaves and stems. . . . .

Carefully measured sections show that the Puget formation contains more than 125 beds which would attract the attention of a prospector searching for coal. They range from one to sixty feet in thickness, and the workable coal beds in any one section vary from five to ten in number. The valuable coal is found in the lower 3000 feet of the formation as at Carbonado, Wilkison, Burnett and Green River.

The Puget formation contains an abundant flora. Fossils are found throughout the Puget formation. These are brackish-water forms. No marine forms have been found in the Puget beds. Willis thinks the beds were laid down in an estuary in which the northern Cascade range formed a peninsula, and the Olympic Mountains an island.[1]

In 1895–6 Willis made collections "from definitely determined stratigraphic horizons on Green River, above Burnett, on South Prairie Creek, and on Carbon River near Carbonado. A preliminary examination of the fossil plants enables Knowlton to report that the lower beds of the series are Eocene, whereas the upper beds may be of Miocene age. . . . . The measured sections of the Puget series exhibit a total thickness of 5800 feet on Green River, 5500 feet on South Prairie Creek, and 5480 feet in Carbon River Canyon. None of these measures is complete. . . . . The sections probably overlap. . . . ."[2]

[1] Cf. CLARK: loc. cit., p. 197.

[2] WILLIS: Bull. Geol. Soc. Amer., Vol. IX, pp. 5, 6, 1898.

On the evidence furnished by fossil plants Sir William Dawson correlates the Puget formation with the Fort Union formation as will be seen from the following quotation:[1]

> In summing up the results of this study of fossil plants from the Tertiary of southern British Columbia, it appears from a comparison with the flora of the Upper Cretaceous Nanaimo series, that the Burrard's Inlet species are distinct and of more modern aspect. On the other hand they are also distinct from those of the older Oligocene or older Miocene deposits of the Similkameen district and other parts of the interior of British Columbia. Between these they occupy an intermediate position; in this respect corresponding with the Laramie of the interior plains east of the Rocky Mountains. They also resemble this formation in the general facies of the flora, which is not dissimilar from that of the Upper Laramie or Fort Union group. We may thus refer the plants [from Burrard's Inlet] now in question to the Paleocene or Eocene, and regard them as corresponding with those of the Atanekerdluk beds in Greenland, the lignitic series of the McKenzie River, and the beds [Kenai?] holding similar plants in Alaska. Thus the opinion expressed in 1890, from the very small collection then available was substantially correct; and I find that the late Dr. Newberry had arrived at a similar conclusion from the study of the plants of the Puget group in Washington territory. This flora thus serves to fill up one of the gaps in our western series of fossil plants, namely, that between the Cretaceous and the Lower Miocene. How completely it may fill this gap we do not know at present. . . . .

THE ARAGO FORMATION

The typical outcrop of this formation is at Cape Arago, Oregon. The beds are chiefly sandstones and shales, and dip toward the northeast at an angle of about 30°. Their thickness is 3000 feet. They contain characteristic Eocene fossils.[2] Diller[3] divides the Arago formation at Coos Bay into the Pulaski formation and the Coaledo formation. The Pulaski is the lower. "The Coaledo formation is characterized not only by the presence of coal, but also by the relatively large proportion of beds containing brackish-water fossils. In the other portion [Pulaski] of the Arago formation of the Coos Bay

[1] SIR WILLIAM DAWSON: Proc. Roy. Soc. Can., n. s., Vol. I, pp. 150, 151, 1895.

[2] DALL: Eighteenth Ann. U. S. Geol. Surv., 1895–6, Part II, p. 343.

[3] Nineteenth Ann. Rep. U. S. Geol. Survey, 1897–8, Part III, p. 320.

quadrangle more than mere traces of coal do not occur, and strata containing brackish-water fossils are rare."[1]

THE MARINE FORMATIONS

THE MARTINEZ FORMATION

The name Martinez was first applied by Gabb[2] to a division of Cretaceous rocks of California. The name comes from the town Martinez, near which typical exposures occur. In recent years the formation has been studied critically by Stanton and by Merriam. "Mr. Stanton has shown the Martinez of Gabb to consist of two parts, one characteristic Cretaceous and inseparable from the Chico group, the other being more closely related faunally and stratigraphically to the Tejon-Eocene than to Chico."[3] The latter was called Lower Tejon by Stanton. Merriam observes that at numerous points on the Pacific coast where the Tejon has been found it always contains an easily recognized fauna. From studies of the faunas in the vicinity of Martinez he proposes (following a suggestion of Stanton) to apply the name Martinez to the Lower Tejon of Stanton.

> In the vicinity of Martinez, the Martinez and Tejon groups form an apparently conformable series between two and three thousand feet in thickness and about equally divided between the two. The faunas, though overlapping, are in the main quite distinct. . . . While some intermingling of species exists, it is not greater than we should expect to find in adjoining groups or periods. . . . The two sets of strata, or two faunas, while belonging perhaps to the two series, represent different periods in the geological history of California, periods quite as distinct so far as faunal evidence is concerned, as the Miocene and Pliocene, or the Pliocene and Quaternary.[4]

The Martinez formation is characterized as "comprising, in the typical locality between one and two thousand feet of sandstones, shales and glauconitic sands," forming "the lower part of a presumably conformable series, the upper portion of which is formed by the Tejon. It contains a known fauna of over sixty

[1] DILLER: loc. cit., p. 320.

[2] Cf. MERRIAM: JOUR. GEOL., Vol. V, p. 767, 1897.

[3] MERRIAM: loc. cit., p. 768.

[4] MERRIAM: loc. cit., p. 774.

species of which the greater portion is peculiar to itself."[1] Its fossils are marine.

THE TEJON FORMATION

This formation was named[2] in 1869 by Whitney, from Fort Tejon, Cal. "The deposits are chiefly conglomerates, sandstones, and shales, in which beds of lignite are not infrequently intercalated, and which less often contain bands of calcareous rock." Clark[3] quotes Whitney (?) as stating that "The conglomerates are very coarse, containing many bowlders from three to six inches in diameter of granite and metamorphic rocks. . . . Portions of the sandstones are very fossiliferous. . . . The strata are very much disturbed, both dip and strike being very variable. . . ." The fossils are marine. Beneath the Tejon is the Chico formation. White, Becker and others state that the Tejon of California lies conformably upon the Chico — the two forming one series.[4] Yet writing of the series at New Idria, Cal., White says, "There is near its middle, a recognizable change of aspect of the strata. . . ."[5] Becker says "The Tejon strata of New Idria are mostly heavy-bedded sandstones of a peculiarly light color, which thus distinguishes them from the tawny Chico standstones."[6]

It is stated also that the Miocene overlies the Tejon conformably. But near Martinez Merriam has shown a pronounced change of fauna, as has been already mentioned. Diller[7] has shown that "All of the facts yet known indicate that in Oregon and northern California there is a faunal and stratigraphic break between the Chico and the Tejon." Perhaps the conformity reported from southern California will be found to be local, or only apparent. Certainly the structural and faunal relations already discussed separate the Tejon from the Chico and from the Martinez. The Tejon is a distinct formation. Near Merced falls, near the boundary of Merced and Mariposa counties,

[1] MERRIAM: loc. cit., p. 775.
[2] Cf. CLARK: loc. cit., p. 100.
[3] CLARK: loc. cit., p. 101.
[4] Cf. CLARK: loc. cit., p. 102.
[5] Quoted by Clark, loc. cit., p. 102.
[6] *Ibid.*
[7] Bull. Geol. Soc. Amer., Vol. IV, p. 220

California, Turner and Ransome describe[1] small patches of Tejon sandstones capping the hills. "This rests almost horizontally upon the nearly vertical edges of the Mariposa [Jura-Trias] slates. . . . The sandstones are overlain to the west by the light colored sandstones of the Ione formation. The two series are probably not absolutely conformable, as the Ione transgresses onto the rocks of the Bed-rock series farther west." Tejon fossils are found in this formation. The Tejon is found in Oregon in the valley of the Willamette River at Albany and at other localities. Clark states that "The Tejon strata of Oregon have been found in a few widely separated localities in the central and northern portions of the state. The most southern yet observed is Coos Bay."[2] But he cites no literature on the the subject, and Diller, in his discussion of the "Coos Bay Coal Field,"[3] makes no mention of Tejon strata.

The Astoria beds at the mouth of Snake River are regarded as Oligocene.

THE UMPQUA FORMATION.

The Eocene described in the Folio of the Roseburg quadrangle, Oregon, rests directly upon an eroded surface of the Upper Cretaceous (Myrtle) formation.[4] There are evidences of considerable erosion in the region before the deposit of the Eocene beds. This leads Diller to believe that Chico may have been present and eroded away. Diller describes the Eocene sedimentary beds under the names "Umpqua formation," from the Umpqua River on which the outcrops occur: "Wilbur tufflentils;" and "Tyee sandstone." The most extensive and important of these is the Umpqua. It lies unconformably upon Cretaceous rocks, and "stretches far beyond the Roseburg quadrangle and plays an important rôle in the makeup of the whole country west of the Cascade Range." The

[1] Geol. Atlas of U. S., Sonora Folio, Calif., 1897.

[2] U. S. Geol. Surv., Bull. 83, p. 103.

[3] Nineteenth Ann. Rep. U. S. Geol. Surv. for 1897–8, Part III, Economic Geology, p. 309 et seq.

[4] DILLER: Geol. Atlas U. S., Roseburg Folio, Ore., 1898.

"formation is composed of an extensive series of conglomerates, sandstones and shales, with terraces here and there of calcareous siliceous beds, which, although of small extent, on account of their exceptional character are treated separately as the Wilbur formation."[1] The Umpqua formation has a maximum exposure of about twelve thousand feet The beds thicken toward the northwest. The bowlders of the Umpqua formation become larger toward the east and south, showing that the land from which they were derived lay in this direction. In places the Umpqua contains abundant marine fossils, *Cardita planicosta* and *Turritella uvasaria* being typical Eocene forms. Thin, small beds of coal also occur.

THE TYEE SANDSTONE

The Tyee sandstone occupies a small area in the vicinity of Roseburg, Ore. "It immediately overlies the Umpqua formation, from whose sandstones it differs chiefly in being heavier bedded and containing more conspicuous scales of mica."[2] It reaches a thickness of about 1000 feet. In places it contains characteristic marine Eocene fossils. The position of the Umpqua and Tyee beds in the geological column cannot be given with certainty. They overlie the Myrtle beds which, according to Stanton, belong to "the lower half of the Upper Cretaceous."[3] Upon the Umpqua, in apparent conformity, lies the "Oakland limestone-lentils" of "probably Oligocene, most likely Upper Oligocene" age.[4] From these relations, from their geographical position and from their fossils I place the Umpqua and Tyee provisionally in the column above the Tejon. If this be their true position they form the latest marine Eocene beds known on the Pacific coast.

THE ATURIA FORMATION

The Aturia beds occur at the water's edge at Astoria, Ore. Formerly they were not distinguished from the overlying shales and sandstones. But in 1880 Condon[5] showed that they are

[1] DILLER: loc. cit. [2] *Ibid.* [3] Quoted by Diller, loc. cit.
[4] DILLER: loc. cit. [5] Amer. Naturalist, Vol. XIV, 1880.

distinct and that the presence of *Aturia ziczac* determines these lower beds to be Eocene or Oligocene. The overlying shales and sandstones do not contain this fossil and are regarded as Miocene. In his "Correlation tables of Tertiary formations: data to 1895" Dall places the Aturia beds in Lower Oligocene, Astoria shales in Upper Oligocene, and Astoria sandstones in Miocene.[1]

UNFOSSILIFEROUS FORMATIONS

THE SPHINX CONGLOMERATE FORMATION

Sphinx conglomerate is the name applied by Peale[2] to a group of nonfossiliferous beds covering an area of about two square miles, but having a thickness of 2000 to 3000 feet. The formation occurs in the Madison Mountain range, Montana. The beds consist of "reddish sandstones and coarse conglomerates of limestone pebbles and bowlders cemented with a reddish sand." They are horizontal and stratified. They are described and mapped as Eocene.

THE PIÑON CONGLOMERATE FORMATION

Weed describes[3] briefly, under the name Piñon conglomerate, certain beds which occur in the southern part of the Yellowstone National Park. He says they consist of a series of conglomerate beds with local intercalations of sandstone, the formation resting unconformably upon the upturned Laramie (Cretaceous)." No fossils are mentioned and they are presumably nonfossiliferous. They are described and mapped as Eocene.

THE SAN MIGUEL FORMATION

The San Miguel formation was named by Purington[4] and referred by him to the Eocene "because of the great unconformity at its base and because it underlies the volcanic complex, which is thought to be of Eocene age in the portions here developed." It occurs near Telluride and Silverton, Col., and rests

[1] Eighteenth Ann. Rep. U. S. Geol. Surv., 1895–6, Part II, pp. 327–348.

[2] Geol. Atlas of U. S., Three Forks Folio, Mont., 1896.

[3] Geol. Atlas of U. S., Yellowstone National Park Folio, 1896.

[4] Geol. Atlas of U. S., Telluride Folio, Col., 1899.

unconformably upon Mesozoic and Paleozoic strata. No fossils have been reported from it. It consists of a coarse, variable conglomerate. Its thickness varies from a few feet to 1000 feet. It is thicker toward the west and dips toward the east.

Some geologists, however, would dispute the right of the San Miguel formation to a place among the Eocene formations on the grounds on which Purington places it there. If it is admitted to the Eocene epoch, there would seem to be no good reason for excluding a number of other formations, among which are the Denver and the Arapahoe beds. Geologists appear to be not fully agreed upon the criteria that shall determine the base of the Eocene.

INTERPRETATION

Having reviewed the various Eocene formations of the region, we may now consider some of the conditions presented by the region as a whole, and some of the problems involved in its history.

Physiography and Climate.— On the Pacific coast the Tejon as now known was deposited in marine water which occupied the great valley of California and western Oregon. It is not known whether the beds of Oregon and California were connected with each other or not. This interior sea in which the Tejon of California was deposited probably connected with the ocean in southern California. There may have been several connecting channels. No definite knowledge exists upon the subject. Before the end of the Tejon deposition the Chico area in Oregon, which had been land and subject to erosion, went down beneath the sea, and beds of Upper Tejon age, possibly underlain by Martinez, were deposited upon it. Probably the same subsidence admitted the sea in which the Umpqua and Tyee beds were deposited a little farther to the southwest. If so, these beds are to be correlated with the Tejon. The correlation of these geographically separated beds must finally be decided by their fossils.

The plants of the Kenai formation indicate a temperate climate at the time of their growth. This climate probably

prevailed over North America, Greenland and Europe, reaching to Spitzbergen. Dall says[1] it may be considered as reasonably certain "that the period during which in the arctic regions the last temperate flora flourished was in a general way the same for all parts of the arctic. It would seem highly improbable that a temperate climate should exist in Spitzbergen and not at the same time in Greenland and Alaska, or *vice versa*." Moreover the nature of the plants of the regions named forms the basis of this statement. The Kenai beds are regarded as fresh water deposits and represent a low land area, which was subsequently still further depressed allowing the Miocene sea to cover it. Dawson[2] says:

> It would be rash to decide on the climatal conditions on the west coast of America in the Eocene period, from the plants yet known. But so far as they can give information we may infer that the Cretaceous climate was somewhat warmer than that of the Eocene, but that both attained a higher temperature than that of the present day in the same latitudes, while in the Miocene age the climatal conditions were not very different from those now prevailing in the region.

The Fort Union beds are perhaps the oldest that have been certainly determined to be Eocene. They occupy the plains region of the north. Their limit to the south is unknown, but Haworth[3] believes that near the beginning of Eocene time Tertiary deposits spread continuously from the Dakota-Nebraska area over western Kansas, Indian Territory, and Texas.

Immediately succeeding or perhaps in part contemporaneous with the Fort Union deposits a series of so-called lake deposits was formed on the plains of the summit region bordering the Rocky Mountains on the east. Elevation or warping of the continent and especially of the mountains of this region appears to have checked the drainage in certain directions, so as to form lakes. The oldest and lowest of these deposits are toward the south and west (Puerco); the newest and highest toward the north and east. Probably during Eocene time the uplift in this

[1] Seventeenth Ann. Rep. U. S. Geol. Surv. 1895–6, Part I, p. 839.

[2] Proc. Roy. Soc. Can., n. s., Vol. I, p. 151, 1895.

[3] The Univ. Geol. Surv. of Kans., Vol. II, p. 253, 1896.

region was greater in the southwestern part than in the northeastern part.

THE ORIGIN OF THE SO-CALLED LAKE DEPOSITS

The stratified deposits of the Wasatch, Bridger, Uinta, and others of like nature have been regarded and referred to as lake deposits. Dutton seems to have been the first to recognize and to point out the fact that some of them are not of lacustrine origin. As early as 1880, in his report on the High Plateaus of Utah he says:[1]

> There is another class of conglomerates which claims our special attention. These are of alluvial origin, formed, not beneath the surface of the sea nor of lakes, but on the land itself. They do not seem to have received from investigators all the attention and study which they merit. . . . . Throughout great portions of the Rocky Mountain region they are accumulating today upon a grand scale and have accumulated very extensively in the past.

He then describes the formation and coalescence of alluvial cones containing well-stratified material. Yet this idea of subaërial deposition seems not to have been further emphasized either by Dutton or by others. For a little later he writes[2] "The whole region [High Plateau], with the exception of the mountain platforms and preëxisting mainlands, has passed through this lucastrine stage."

In 1896 Gilbert[3] clearly interpreted certain stratified deposits of Colorado as fluviatile. He speaks thus of the Upland sands and gravels of the Arkansas River basin:

> Whatever the cause the streams which flowed from the mountains onto the plains, and thence eastward across the plains, ceased to carve valleys in the region of the plains, and began to deposit sediment. When they had filled their channels so that their beds lay higher than the neighboring country, they broke through their banks, shifting their courses to new positions and they then came to flow in succession over all parts of the plains, and to distribute their deposits widely, so that the whole plain of the district here described was covered by sands and gravels brought from the canyons and valleys of the Rocky Mountains.

[1] Geol. of the High Plateaus of Utah, pp. 219 et seq., 1880.

[2] The Grand Canyon of the Colorado, p. 216, 1882.

[3] Seventeenth Ann. Rep. U. S. Geol. Surv. for 1895–6, Part II, pp. 575, 576.

In studying the Tertiary deposits of Kansas Haworth reaches similar conclusions. He says:[1]

> The relative positions of gravel, sand and clay of the Tertiary over the whole of Kansas . . . . correspond much better to river deposits than to lake deposits. . . . It is quite possible that during Tertiary time . . . . lesser local lakes and lagoons and swamps and marshes may have existed in different places and for varying lengths of time. But when we consider the Kansas Tertiary as a whole and yet in detail, it must be admitted that the materials themselves have many indications of river deposits and a very few of lake deposits.

Matthew,[2] in discussing the question whether the White River Tertiary is an eolian formation, considers the objections to the lacustrine hypothesis and gives reasons for his believing it to be of eolian origin. He reaches the conclusion that the "White River clays in Colorado, at least, are chiefly eolian deposits. . . . . Most of the sandstones are probably fluviatile. . . . . Some sandstones may be eolian" (407). This position, however, cannot at present be regarded as established; but the question of lacustrine origin is shown to be an open one.

In 1897 Davis,[3] in discussing the origin of the Denver formation, gives criteria for distinguishing lacustrine from fluviatile deposits. In a later publication[4] the same author compares lacustrine with fluviatile deposits as follows: "In both cases the deposits are stratified; in both cases the deposits may include fine as well as coarse materials; in both cases the area of distribution may be large as well as small; in both cases the thickness of deposits may be great as well as light; in both cases the strata may bear ripple-marks, mud-cracks, cross-bedding, and other indications of small and variable water-depth. With all these similarities, it would not be remarkable if a lake deposit were sometimes called a river deposit, or if a river deposit were

[1] The Univ. Geol. Surv. of Kans., Vol. II, p. 283, 1897.

[2] Amer. Naturalist, Vol. XXXIII, pp. 403–408, 1899.

[3] Science, U. S., Vol. VI, pp. 619–621, 1897.

[4] Freshwater Tertiary Formations of the Rocky Mountain Region. Proc. Amer. Acad. Arts and Sci., Vol. XXXV, pp. 345–373, 1900.

mistaken for a lake deposit; for the safe discrimination of the two classes of deposits must depend on their differences, not on their resemblances. While the marginal sediments of a lake may be coarse, the body of the central sediments must be fine and uniform. The marginal parts of a fluviatile deposit may also be coarser than the forward parts, but the latter may be characterized by frequent variations of texture and structure, and occasionally by filled channels and lateral unconformities" (p. 371).

Some quotations may be given to show that many descriptions of the so-called lake beds would apply equally well to river deposits. Lake terraces are "well marked between Ralston and South Boulder creeks (Colorado), where there is a *blending of lake and river terraces.*[1] Here five distinct terraces are traceable, the lake terraces extending from 100 yards to three miles eastward from the foothills, while those more distinctly of stream origin are from 200 to 700 feet in width."[2] Here the lake and river terraces are not clearly distinguished: the width of the terrace seems to be the principal criterion, and the limits assigned to lake and to river terraces overlap. According to the figures given, the river terraces here reach a width of 700 feet, while some of the lake terraces are only 300 feet wide. Again, from the same monograph, with reference to the present inclination of both Tertiary and Pleistocene deposits, it is said that there is an inclination "in round numbers of ten feet to the mile from the foothill region to the valleys of the Missouri and Mississippi;" this would not admit of the holding of lake waters."[3]

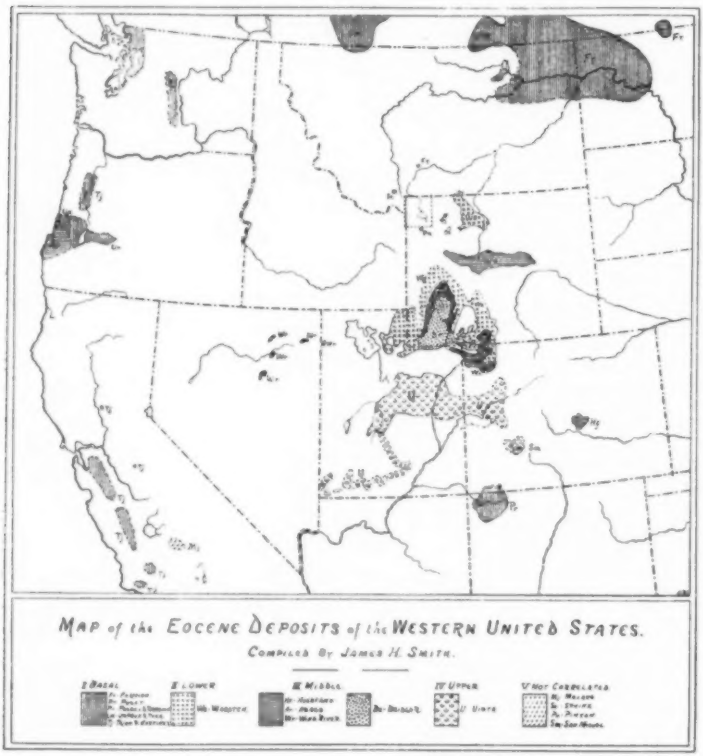
King's Report of the Survey of the 40th Parallel abounds in descriptions of so-called lake beds like the following: "Rough, gritty conglomerates, passing up into finer-grained sandstones, and at certain points developing creamy, calcareous beds" (p. 405). The most characteristic exhibition is in the basin of Vermillion Creek, where a fuller section is displayed. It is made up

[1] The italics are mine.

[2] EMMONS: Geol. of Denver Basin, Monograph XXVII. U. S. Geol. Surv., p. 9, 1896.

[3] *Ibid.*, p. 40.

of a heavy, gritty series at the base. . . . . The middle members are of finer material and are more intercalated with clays, ... while the upper part of the series . . . . is made up of striped and banded sandstones varying from gray to yellow, white and red, with prevailing red and white tints" (p. 375).



Enough has been said, perhaps, to show that no single explanation will account for the deposition of all the so-called lake beds. At present it seems probable that the deposits will be found to be in part lacustrine, in part fluviatile, and possibly in part eolian. The origin of these deposits cannot be solved by

theoretical considerations alone. Only extensive, critical study in the field will furnish the data upon which the final conclusions must be based. It will be well if the investigator shall enter the field with a clear knowledge of the facts already known, with the possibilities of the different modes of deposition and with the criteria for distinguishing these modes well in mind; and with a willingness to be led to any conclusion to which the facts may conduct him.

CORRELATION TABLE[1]

Eocene	Pacific Coast	Interior	European
Upper	Foraminiferal Shales (?)	Uinta / Bridger (upper part)	Ligurien
Middle	Arago	Bridger: Bridger-Huerfano (upper) / Wind River-Huerfano (lower)	Bartonien / Lutetien
Lower	Kenai (?)	Wasatch	Suessonien
Basal	Tyee / Umpqua (?)		
	Tejon	Torrejon	Thanetien
	Martinez	Puerco	Montienj
	Puget	Fort Union	

JAMES HERVEY SMITH.

[1] Cf. DALL: Eighteenth Ann. Rep. U. S. Geol. Surv., Part II, table facing p. 334, 1897. SCOTT: Science, n. s., Vol. II, p. 499, 1895. Also Introduction to Geology, p. 496. OSBORN: Science, n. s., Vol. XI, p. 562, 1900.

Many Eocene formations, not yet correlated, are omitted from the table.

EDITORIAL

DURING the spring of 1900 the Director of the United States Geological Survey has planned, with the approval of the Secretary of the Interior, an important reorganization of the Geologic Branch. In order that the significance of this step should be appreciated in all its bearings, it is desirable briefly to review the history of the administrative and scientific control within the survey. In the First Annual Report Mr. King set forth a plan of organization based on grand geographic and geologic provinces. The work being then restricted to the national domain west of the 101st meridian, four divisions were established, that of the Rocky Mountains under Emmons, that of the Colorado under Dutton, that of the Great Basin under Gilbert, and of the Pacific under Hague. Each of these divisions corresponded to a province within which the geological phenomena had a certain unity of history and character, and it was wisely argued that the work in each should be directed by a geologist familiar with the special problems of the area entrusted to him. At the same time the limited appropriations of the survey and the adopted policy of surveying the most important mining districts led to a concentration of effort upon Leadville, Eureka, and the Comstock Lode, so that initially comparatively little progress was made in solving the broad geologic problems presented to each division. The principal contributions which the West yielded to the philosophy of the science were made by the surveys through whose consolidation the Geological Survey was created. With the growth of the survey and the addition to its corps of many of the leading minds in American geology, more numerous geographic divisions were established and their limits became more artificial. Thus in the Sixth Annual Report we find enumerated, in addition to the ones first established, the Division of Glacial Geology (Chamberlin), the Division of Volcanic Geology

(Dutton), the Division of the Crystalline Schists of the Appalachian and Lake Superior Regions (Pumpelly and Irving respectively), the Appalachian Region (Gilbert), and the Yellowstone Park (Hague). As divisions became more numerous and restricted, the administrative machinery became more complex, and the opportunities afforded the geologists in charge to study broad problems became more and more limited. Finally it was found that the administrative relations were not only difficult but expensive, since they involved the maintenance of independent offices and clerks, and in the interests of economy and efficiency the system of geographic divisions was abolished in 1893. In its place was substituted an organization by parties, of which there were at first twenty and subsequently nearly double that number, each acting independently of the other except in so far as they were all brought into coöperation through the Director and the Assistant in Geology. Broad coördination of scientific work was for the time being subordinated to the accumulation of facts, especially in the form of geologic maps, rather than to the consideration of philosophic problems. After six years of this activity in the working out of special problems, the time has come for broader supervision and coördination of work, and to this end the following appointments have been made:

GEORGE F. BECKER, Geologist in Charge of Physical and Chemical Research.

T. C. CHAMBERLIN, Geologist in Charge of all Pleistocene Geology.

S. F. EMMONS, Geologist in Charge of Investigation of Metalliferous Ores.

C. WILLARD HAYES, Geologist in Charge of Investigation of Non-Metalliferous Economic Deposits.

T. W. STANTON, Paleontologist in Charge of Paleontology.

C. R. VAN HISE, Geologist in Charge of Pre-Cambrian and Metamorphic Geology.

BAILEY WILLIS (Assistant in Geology to the Director), Geologist in Charge of Areal Geology.

The field of supervision of each geologist in charge is coextensive with the work of the Geological Survey and relates to all parties engaged in work connected with his special subject. His assistance in field or office work may appropriately be

offered or invited. His opinion is to be considered authoritative in subjects under his supervision, and his approval to any report may be required. This authority, however, is restricted to the scientific aspects of the work. Administrative direction remains as heretofore wholly in the hands of the Director, and the work of the survey will proceed after the manner which has been found successful, of authorization of plans of operations after full consideration and conference upon estimates submitted by geologists in charge of parties.

Under the organization now adopted, each geologist is at liberty to make full use of the facts which he observes within his field of operations, the degree of supervision exerted by the geologist in charge of any particular subject to be duly credited in an appropriate manner. For the geologists in charge the plan affords an opportunity to study a special subject in all its aspects throughout the field of operations of the survey, either directly by personal observation or by conference with associates. This opportunity is unequaled in both multiplicity and magnitude of the phenomena presented to each specialist.

B. W.

Reviews.

Department of Geology and Natural Resources of Indiana, Twenty-fourth Annual Report. By W. S. Blatchley, State Geologist. Indianapolis, Ind., 1899.

The current report is a healthy-looking volume of 1078 pages, devoted mainly to the natural history of the state, exclusive of geology. It is well printed and bound, and but one criticism need be made of its typographical make-up, namely, that the title upon the back is not uniform in style and does not align with the titles of preceding volumes; nor they with each other, for that matter.

W. S. Blatchley (pp. 3–40) gives a brief résumé of the natural resources of the state, embodying the salient points appearing in previous reports of the department, together with such facts and statistics as have been brought in the recent work of the department.

Aug. F. Foerste (pp. 41–80) in an interesting paper discusses the synonomy and correlation of the Middle Devonian of Indiana, Kentucky, and Ohio, as embraced in the Cincinnati Anticlinal Region. The formations involved are the Madison beds (Upper Ordovician), Clinton, and Osgood Shale (Lower Niagara). The Madison beds, unfossiliferous and somewhat arenaceous, have caused much confusion, being variously classed as Clinton, Medina, and Ordovician. The various formations referred to the Medina around the flanks of the Cincinnati Anticline are to be correlated with the Madison beds. The oolitic iron-ore facies of the Clinton does not appear west of the Cincinnati axis, the Clinton being represented by a thin, salmon-colored limestone.

The author's opinions regarding the date of the Cincinnati Uplift may be quoted here in advance of the fuller conclusions promised at an early date. "The considerable variation in thickness of these limestones . . . . suggests that the Clinton lies unconformably upon the Lower Silurian, and that this unconformity could be well established if a careful study of this problem were made. The writer was, however, not able to find anything suggesting that this unconformity was in any way related to the formation of the Cincinnati axis. If the

elevation of the Cincinnati axis began in Middle Silurian this still remains to be proved. There is ample proof of local elevations in various parts of Indiana, Kentucky, and Ohio, but not of any connection between these elevations and the formation of the Cincinnati axis. . . . . The result of all my investigations for the last five years in Ohio, Kentucky, and Indiana have tended to confirm the conclusion that at the close of the Upper Silurian a considerable part of the folding which now constitutes the Cincinnati axis took place; that a period of denudation took place, removing most strata from the axis of this fold, and proportionally smaller amounts from its flanks; and that the Devonian rests unconformably upon the denuded Upper Silurian rocks upon the flanks of the axis, and that it rests upon Lower Silurian upon the middle portions of this axis."

J. A. Price (pp. 81–143, with map) outlines the distribution of the Waldron shale (Upper Niagara) through Decatur, Rush, Shelby, and Bartholomew counties, and gives numerous detailed sections covering the Devonian-Silurian parting. The name Hartsville limestone is proposed for a bed of limestone ranging up to ten feet in thickness, lying between the Waldron shale and the Devonian limestone. It is considered to be Silurian in age and as probably the equivalent of the Louisville limestone of Foerste. An interesting case of postglacial stream diversion is noted in the northwestern part of Decatur county. Flat Rock and Little Flat Rock creeks, flowing in southwesterly directions through old valleys, join near Downeyville and flow west through a narrow valley. From near the junction an old col extends to the present valley of Clifty Creek, near Milford. The glacial and preglacial course of the two branches of Flat Rock was through this old col and down Clifty Creek. Later they were diverted into the present valley of Flat Rock.

E. B. Williamson (pp. 229–333, pls. I–VII) on the Dragonflies of Indiana, gives keys for their identification, directions for collecting and preserving, and descriptions of those species known to occur in the state.

R. E. Call (pp. 335–536, pls. I–LXXVII) contributes a most complete and well-illustrated descriptive catalogue of the mollusca of Indiana, including bibliography, keys, and notes on the habits and distribution of all forms found in the state.

W. S. Blatchley (pp. 537–552) in a brief paper describes the batrachians and reptiles of Vigo county.

Stanley Coulter (pp. 553–1002) gives a comprehensive catalogue of the flowering plants, and ferns and their allies, indigenous to the state. The paper includes a bibliography and a voluminous introduction, with sections on the ecologic distribution of the plants (particularly those of the dunes), re-forestation, poisonous plants, and noxious weeds.

The reports of the state inspectors of mines, gas, and oil are also incorporated into the report. From these we learn that the production of coal for 1899 exceeded by 14 per cent. that of any preceding year, while the petroleum product shows an increase in value of 50 per cent. The average rock pressure in the natural-gas field is 155 pounds, as compared with 173 pounds in 1898, foreshadowing the early exhaustion of this popular fuel.

C. E. S.

The Geography of the Region about Devil's Lake and the Dalles of the Wisconsin, with some notes on its Surface Geology. By ROLLIN D. SALISBURY and WALLACE W. ATWOOD. Bulletin No. 5, and No. 1 of the Educational Series of the Wisconsin Geological and Natural History Survey. Published by the State. Madison, Wis., 1900.

It is seldom that a state report is readable for one who is not a geologist, or of more than local interest; but the bulletin just issued by the Wisconsin Geological and Natural History Survey is an exception. The bulletin is a volume of 151 pages with 39 plates and 47 cuts. It is one of the handsomest volumes ever issued by a state survey. The photograph is the best medium for describing nature clearly and sharply, and it has been used to good advantage throughout the report.

The report is a description of the geography and surface geology about Devil's Lake and the Dalles of the Wisconsin. Perhaps there is no region in the interior where more objects of geological interest are found in an area of a few square miles than in the territory about Devil's Lake. All the various types of topography developed by glacial action are seen in contrast with those of the driftless area, and several problems in structural geology are presented. River phenomena especially those connected with the ice invasion, are numerous. One of the best features of the book is the illustrations. The mechanical work is excellent, and each plate is typical of what it illustrates.

The book is divided into two parts: Part I describes the topography, and Part II gives the history of it development.

The quartzite ridges are the most prominent geographic features. In several places they rise to a height of 800 feet above the Wisconsin River and extend for over twenty miles in a general east-west direction. In no place is the quartzite found in horizontal beds, the dip varying between 15 and 90 degrees. Upon and against the quartzite are horizontal beds of sandstone which have been deformed but little; the sandstone topography, modified by the drift, forms the second great geographic feature of the region. It is found north and south of the quartzite ranges, and between them along the valley of the Baraboo.

The first chapter in Part II gives an outline of the history of the formations which outcrop about Baraboo. It is shown how the quartzite was changed from loose sand to quartzite and how deformation and metamorphism were developed during the uplift. The question as to the amount of erosion before the deposition of Cambrian sediments is discussed, but no definite figures can be given. The same is true as to the thickness of the quartzite. After the quartzite had been eroded for a long interval of time, geographic changes caused the sea to again cover the region and the Paleozoic strata were laid down unconformably on the eroded and folded quartzite.

Some time in the Paleozoic, perhaps at the close of the Niagara, the region was again uncovered by the sea, and the work of erosion was begun anew upon the sediments which now completely covered the quartzite bluffs.

In chapter III is given a concise treatment of rain and river erosion, adapted to the area in hand. The question of base-leveling is also discussed. Chapter IV is given over to the description of striking scenic features about Baraboo such as Devil's Lake, the Narrows, Parfrey's and Dorward's Glens, the Dalles of the Wisconsin, Natural Bridge and Castle Rock.

Chapter V deals with the glacial period and is the longest and most important in the book. The first part of the chapter is devoted to a discussion of ice, ice action, and the general results of an ice invasion. As far as possible the illustrations are taken from the region of Baraboo.

The last part of the chapter deals with the changes in drainage effected by the ice. At the time the ice was on, much of the country to the west was covered by large lakes. As the ice retreated these lakes

were drained, giving rise to many smaller bodies of water. The remnants of some of them are still in existence.

The bulletin will be useful to teachers and to geologists in general. Good use can be made of it as collateral reading in the class room. It is No. I in the Educational Series of the Wisconsin Geological Survey and is intended for use in schools. It is an innovation in state survey work and will be of great help in the teaching of geography and geology.

F. H. H. C.

A Preliminary Report on a Part of the Clays of Georgia. By GEORGE E. LADD, Assistant Geologist. Bulletin No. 6 A, Geological Survey of Georgia, 1898.

Preliminary Report on the Clays of Alabama. By HEINRICH RIES, Ph.D. Geological Survey of Alabama, Bulletin No. 6, 1900.

The volume on the clays of Georgia contains a general discussion of clays, touching their origin, composition, properties, especially those which affect their commercial value, and a discussion of the modes of handling and testing clays. A chapter is devoted to the "Fall Line" clays, on which the field work in preparation for the volume was chiefly concentrated. The results of this field work, stated in the author's language, were: "First, the tracing of the Cretaceous strata eastward, across the state, thus necessitating a modification of the geological map of Georgia, which has hitherto limited the Cretaceous to a strip of territory, traversing the central western part of the state. Second, the discovery of white kaolin, some of which ranks with the valuable South Carolina deposits as 'paper clay.' Third, the experimental proof that some of these kaolins, suitable for fire-clay, are more refractory than any of the noted fire-clays of the United States."

The clays of the state which are found to be commercially valuable are mainly in the Coastal Plain, and a sketch of the geology and physiography of this part of the state is introduced. The clay industries of the state are reviewed by localities, and some comparatives notes gathered from other states are introduced. The excellent paper and typography of the volume are to be noted as adding greatly to the attractiveness and readability of the bulletin.

The bulletin of the survey of Alabama likewise contains a general discussion of clays, touching the same general points as the discussion

opening the preceding volume. A chapter is introduced by Dr. Smith outlining the geological relations of the clays of the state. The subject is, however, incomplete, since the Tertiary and post-Tertiary clays receive little specific consideration, and it is indicated that they have not been studied in detail.

The clays of Alabama are considered with reference to their physical and chemical properties, and are discussed under the following headings: China clays, which occur in six counties; fire clays, which occur in seven counties; pottery or stoneware clays, which occur in ten counties; and brick clays, which are mentioned in eight counties. This latter class of clays must be far from complete, since the Tertiary and Pleistocene clays appropriate for brickmaking must be very widespread.

In both these bulletins the educational intent is evident for, in both cases the authors appear to have had in mind readers who have no special knowledge of geology. The idea that geological reports should be written for those who are not familiar with the technicalities of the science is fortunately one which is gaining ground, as the recent publications of many state state surveys show.

R. D. S.